

Metal Progress

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Cover was worked up from one of Prof. Murray's photo-elastic studies of a holed plate stressed in tension

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Supplies of strategic and critical metals

STRATEGIC METALS are those essential to the national defense, only a minor portion produced in the United States, and for which strict rationing will be necessary in war. **Critical metals** are those which, while essential to national defense and secured in considerable portion from foreign sources, will be available locally in more adequate quantity.

On Jan. 30, 1940, the Army and Navy Munitions Board approved the following list of strategic and critical metals:

Strategic metals, seven in number: Antimony, chromium, manganese (ferro grade), mercury, nickel, tin, tungsten.

Critical metals, three in number: Aluminum, platinum, and vanadium.

Since temporary shortages have developed quite recently in four other important metals, their consideration is also desirable. These are copper, iron (steel), magnesium, and zinc.

Let us discuss these metals alphabetically, first having remarked that tin and chromium are the two giving most concern.

Aluminum, a critical metal. Demands for aluminum have increased so sharply due to the expanding aircraft program that many items going into the production of the ingot, as well as facilities for the metal's fabrication, have required anxious study. While detailed figures are confidential, being closely related to the production of fighting aircraft, no shortage of ingot aluminum nor essential fabricated forms is anticipated—at least as far forward as July 1942. In some of the products, plant capacity will at times just about

equal anticipated consumption, and under those circumstances temporary delays may be anticipated. No serious and widespread shortage, however, is seen in the figures, and it may be said that at the present time aircraft consumption has not yet reached the tonnages provided for in the confidential estimates.

First, as to the production of virgin ingots: Fortunately, the Aluminum Co. of America, our only producer, started many months ago on a large expansion program, not only near its own power plants in the southern Appalachian region, but also near the Bonneville Dam on the Columbia River. Production as of June 1940 was on the order of 35,000,000 lb. per month, and as these new plants come into produc-

tion and the recovery of secondary aluminum increases slightly, the total supply in July 1942 will double that figure. This includes an estimated 5,000,000 lb. of ingots monthly starting July 1941 from a plant financed by Reconstruction Finance Corp. and built by the Reynolds Metal Co. at Sheffield, Ala.

Of the most important raw materials for the manufacture of ingot aluminum, **power** may be mentioned, and power plants require a lot of time to build, whether generating from steam or waterfall. Fortunately there is a considerable surplus of power now available in various dams built by the Tennessee Valley Authority, and those recently built or nearing completion in the West.

Bauxite, the ore from which aluminum is produced, is stock-piled for a nine months' supply. Slightly over half our bauxite is imported from Dutch Guiana, and there should be little interruption with shipping across the Caribbean Sea. The balance now comes from mines in Arkansas. Deposits in both regions are worked in open pits; not only can output quickly be expanded, but is now steadily mounting. In Arkansas alone we have an eight years' supply of proven ore, even if all our anticipated requirements were taken from that state.

Aluminum, as is well known, is reduced electrolytically from a molten solution of cryolite and aluminum oxide. **Cryolite** comes largely from Greenland; problems of supply would be serious were it not that cryolite is easily made synthetically from soda, aluminum and hydrofluoric acid (the latter being made from fluorspar of which

our entire requirements—including large quantities used as fluxes in steel making—are mined in Illinois and Kentucky).

As to the **fabrication facilities**: Rolling mills for high strength aluminum alloy sheets, such as are used primarily for the fuselages and wings of aircraft, are practically at capacity now. This situation will be relieved within six months by a new mill of the Aluminum Co. of America, to have an ultimate capacity of 10,000,000 lb. of rolled shapes per month. Forging capacity in both large and small hammers exclusively devoted to aluminum is in a tighter situation. While there is more capacity than needed for military requirements at the present time, a shortage is anticipated by July 1941. Some big hammers must be secured, and automobile forge shops are now being surveyed for facilities. Adequate capacity exists, certainly as far as 1941 requirements are concerned, in the manufacture of extrusions and high strength tubing, although a shortage in wire, rods and shapes will require new mill capacity. There apparently is adequate capacity and skilled personnel to manufacture all the sand castings, permanent mold castings and die castings required by the defense program.

Fortunately most civilian uses for aluminum utilize unalloyed metal or softer alloys, and consequently consumption at the 1940 level will not interfere unduly with the production and fabrication of the special forms used for military purposes. Estimated ingot production also is sufficiently large to maintain civilian uses at the 1940 level.

Antimony is a strategic metal, since over a period of years less than 10% of American requirements have come from mines in the United States. In that same time we have consumed approximately half the world's production. Under these circumstances, the work started in 1939 by the United States Geological Survey and the Bureau of Mines is of especial importance. These agencies were instructed to survey existing mines and prospects of all the strategic and critical minerals, and to do enough developmental work on likely deposits to prove the ore body. In one mining district some high grade antimony ore has been discovered in small lenses and it is believed that this constitutes an important reserve. Furthermore, a large low grade deposit of antimony ore has been indicated by extensive diamond drilling which can be mined for a substantial percentage of our requirements if the emergency warrants paying the necessary price.

Meanwhile an antimony smelter has been operating at Laredo, Texas, since 1931, largely on Mexican ores; for this reason Mexican ore has been steadily increasing in volume to where it has practically supplanted metal from China as our principal source of supply. Imports from Bolivia are

also expanding rapidly at the present time, and during 1914-18 about half of our then requirements came from countries to the south of us.

Antimony is used for bearing metal alloys, for hardening lead (battery plates, electric and telephone cable sheathing, bullet cores and shrapnel balls), primer mixtures and pyrotechnics. Our current consumption is about 15,000 tons of new metal supplemented by 10,000 tons of secondary metal. What it will be during another emergency is problematic, as consumption increased relatively little during the last war, even though world production doubled. Many economies could be effected if necessary; the normal 1% antimony-lead cable sheath is already being supplanted by lead hardened with calcium; babbitt for bearings is being economized by using steel-backed bearings with an exceedingly thin layer of alloy on the rubbing surface (which also saves much tin, another strategic metal). Other bearings are common, such as copper-lead, powdered copper and graphite, ball and roller bearings.

With an operating smelter within our own borders, rapidly expanding ore shipments from Mexico and Bolivia, and emergency production from numerous small mines in America, as well as the use of substitutes proven to be quite adequate, we are not likely to be in serious trouble from a lack of antimony.

Chromium, a strategic metal, looks upon a situation which is by no means so easy. In October 1940 JAMES H. CRITCHETT, vice-president of Electro Metallurgical Co., leading producer of ferrochromium, wrote in METAL PROGRESS: "The manufacturers of ferrochromium, refractories, and other chromium products have always maintained large stocks amounting in cases to several years' requirements under normal conditions and to more than a year's needs under even the most exaggerated demands." Some dependence might also be placed in the stock-pile of metallurgical ore being accumulated by Metals Reserve Co. (a governmental corporation). Unfortunately this stock-pile is now growing slowly, if at all, because of the almost complete interruption of shipments from the countries bordering the Mediterranean, ordinarily a prime source.

Meanwhile the world's requirements for chromite (the ore of chromium) have doubled within the last ten years. In 1930 one ton of chromite sufficed for 200 tons of steel but, what with the increasing use of chromite refractories and chromium alloy steels (including the new high chromium stainless steels and heat resisting alloys), one ton of chromite is now sufficient for only 100 tons of steel. If this world trend should hold for America, 800,000 tons of chromite containing approximately 200,000 tons of chromium metal would be required for a single year of capacity

steel production in the United States. This is almost 50% more than our record importations in 1937, and nearly three times as much as the total United States mines' production of chromite since the beginning. Large contracts have been let to producers in our usual sources — South Africa, Rhodesia and the Philippines — but available bottoms are becoming scarcer, and those ships which do ply are carrying more lucrative cargo. It results that we are at the present time probably consuming slightly more than we are receiving. There is considerably more than a year's supply of chromite on hand.

Statistics on actual consumption are somewhat muddled by the fact that there are three types of ores imported and required; the most important one, metallurgical ore, should contain a high proportion of chromium in relation to iron in the ore in order to smelt it economically into ferrochromium. Perhaps 45% of the chromite ore is now smelted. Forty per cent of the chromite is used for refractory brick and cement, and in this ore considerable of the chromium can be replaced either by iron or aluminum. The last is "chemical ore" which contains 45 to 50% chromium and comprises about 15% of the imports.

In the last decade our metallurgical ore has come chiefly from Rhodesia, Turkey and New Caledonia (near Australia), all sources now either inaccessible or requiring long ocean voyages. Now the important suppliers of refractory chromite are the Philippines (which has achieved this status in the last five years), Cuba, and Greece. The former two have large reserves; Cuba probably could supply a great part of the American requirements, given time to expand mining operations.

Domestic chromite comes from hundreds of small mines, most of them in the Coast Range. Worked during the last war, they produced about 175,000 tons of chromite at prices ranging up to 6¢ per lb. of chromium oxide, an inflated price considering the current 2¢ quotation. With the general development of motor transport these small prospects will doubtless be more prolific in a new war, but the most hopeful development comes from the Geological Survey and Bureau of Mines. By trenching and diamond drilling a very extensive mineralized zone has been blocked out in the Absaroka Mountains along the Montana-Wyoming

border. It is a low grade ore which can be concentrated by known methods to a usable grade. Exploitation in a large way is now being actively prosecuted by private firms.

Thus, while the situation in chromium might become serious, the general impression seems to be that we can probably "live off our fat" until local supplies are ready.

Copper: While copper is not listed as either a strategic or critical metal, it is an essential of cartridge brass (70% copper, 30% zinc) and of course in the manufacture of all electrical equipment. Until a shortage developed by record sales in September 1940 no concern was felt, since the United States is the leading copper producer, with output normally equaling two out of the three next important producers, namely Africa, Chile and Canada. We also can easily produce 500,000 tons of secondary metal annually, and normally export much copper in finished form. These enormous

resources, together with ample supplies from Chile and Peru, provide for everything but very temporary shortages, yet in order to avoid even this, the Metals Reserve Corp. is to acquire a revolving stock of spot copper. The daily press reported on Feb. 2 that the second purchase of 100,000 tons of South American copper had been made.

Magnesium also is not listed either as strategic or critical, probably because the 12,000,000-lb. per year capacity of the Midland, Mich., plant of Dow Chemical Co. is ample to supply the current demands of the aircraft industry. Additional plant is under construction at Freeport, Texas, to produce magnesium from salts dissolved in sea water; it will start late in the summer of 1941, and will approximately double present capacity. Tentative arrangements are being made to add another 10,000,000 lb. per year to our ingot capacity in 1942. Expansion of rolling and extrusion plant for this added ingot metal will be necessary. Most of the magnesium will be consumed as castings, and in view of the specialized foundry practice required, more foundry capacity and skilled foundrymen will be needed.

Manganese is a strategic metal, very much a strategic metal, but the situation concerning spot supplies is easier now than it was, say six or seven years ago. American interests, in common with those in other steel producing countries, have

PRIOR to a talk on Strategic Metals before the Canton-Massillon Chapter on January 16, the Editor interviewed various members of W. Averell Harriman's staff of specialists in Washington (Mr. Harriman being Commissioner for Industrial Materials in the Office of Production Management) and was permitted to read year-end statements about the expected supply and demand for various essential metals. This enabled him to get a clear and up-to-date view of the situation; however the wording of this article is the Editor's and it must not be viewed as an official statement.

accumulated large reserves; privately held stocks at present are approximately one year's requirement for the U. S. steel industry at maximum capacity, or well over a million tons of ferro grade ore (48% manganese or better). In peaceful times we would expect to get about one third of our annual requirements from Russia, but this source is not now available. Other large sources of supply are the Gold Coast, India, and Brazil. Imports from Brazil can be largely increased over the normal 250,000 tons per year, principally by improvement of transportation facilities to ports. The best source of immediate and nearby manganese ore, however, is Cuba, where exists an enormous deposit of oxide ores containing 13 to 18% Mn. After many years of development, the owning company—a subsidiary of the Freeport Sulphur Co.—has perfected the flotation and nodulizing process to where it is currently producing 50% concentrate at the rate of 130,000 tons annually. Metals Reserve Co. has guaranteed consumption of this amount for a period of years, and the output could be readily increased from the steam shovel pits, now that precise methods have been developed for beneficiation using simple and well-known equipment. Likewise production of manganese carbonate ore from the upper levels of the Butte copper mines has again been resumed; these ores are concentrated by flotation and roasted to a 60% concentrate. Metals Reserve Co. has contracted with this source for 100,000 tons annually for five years.

It results that we have at present about 22 months' supply of manganese in sight for the American steel industry, operating at capacity, and with unrestricted consumption. This could be extended to 30 months with moderate restrictions.

During the last war the normal price of ore (approximately \$20 per ton) went up to a peak of \$60, and a generally high price brought out about 675,000 net tons of a fairly low grade ore (considerably less than the 48% Mn content in the average import). This production, however, dropped off immediately foreign resources were again available. A recent survey by the United States Geological Survey and the Bureau of Mines listed 1300 known small deposits in the West and South, of which 47 warranted exploratory work. It is also estimated that these mines could produce about 3½ million tons of ferro grade ore if \$50 per ton were to be paid. As a result of these surveys, four or five mines in the Appalachian region and in New Mexico have been awarded contracts by Metals Reserve Co. to contribute to the Government stock-pile at prices calculated to enable these properties to operate.

The United States also has enormous deposits of manganiferous iron ore. For instance, there are many million tons of 9% manganese ore in the Cuyuna iron range in Minnesota, and about

100,000,000 tons of nodular material containing 16% Mn and 11% Fe near Chamberlain, S. Dak.

A committee of technologists is cooperating with the Bureau of Mines in a \$2,000,000 study of the problem in laboratory and pilot plant to determine which of the three or four plans of recovering manganese from these low grade ores can best be operated commercially. One was described briefly in METAL PROGRESS for December 1940 and contemplates matte smelting with pyrite or sulphur, and roasting the high manganese matte to a ferro grade ore. Other plans contemplate the manufacture of steel from these ores and the recovery of the manganese from high manganese slag. Still another subjects the ore to an oxidizing roast and leaches out the manganese as sulphate from which solution it is precipitated. (Electrolytic manganese from ore leachings is not competitive with furnace smelted ferromanganese; electrolytic manganese is certainly a meritorious product, but in the present state of its development it makes practically pure manganese at a cost on the order of 25¢ a lb., and in quantities on the order of one ton a day.)

In summary, it may be said that we have approximately two years' visible supply of essential manganese if all sea lanes were closed except to Cuba, and as long as the sea lanes are open, current deliveries to industry and Government stock-pile are at a higher rate than day-to-day consumption.

Mercury is listed as a strategic metal, although possibly "critical" would be a better classification, as it is one rare metal which America was 70 years ago leading in production; likewise our present resources are ample for our own uses. In the past American consumption has paralleled rather closely the selling price; since 1913 we have produced 65% of our own requirements despite competition from high grade, low cost mines in Spain and Italy.

Our annual requirements in good times would be on the order of 28,000 flasks of 76 lb. mercury each. The normal price might be quoted as \$1 per lb. What with the Spanish civil war and the more recent closing of shipments from the Mediterranean, imports declined since 1936 and practically stopped a year ago. This sharp decline was abetted by the Italian and Spanish cartel which doubled the price to us. In fact, the price went as high as \$3 per lb. by mid-1940, and this brought out high American production, October being at the rate of 43,000 flasks per year. Prices then naturally declined, and now are nearer \$2 per lb., which will probably bring out all the mercury necessary.

While there are 107 producing mines in the United States, three or four large ones in California and Oregon produce most of the mercury. Good ore contains about 6 lb. of mercury per ton.

the marginal production comes from mines which have about 3 lb. of mercury per ton of ore, or less. The mineral is the sulphide cinnabar; sulphur roasts off on gentle heating, the mercury volatilizes, and is collected in cooling towers and vapor precipitators.

Mexico has produced perhaps 7000 flasks of mercury per year over a period of years, from a mine which ships to Los Angeles for treatment. This ore also contains antimony as a valuable by-product.

Three quarters of the mercury produced is used in chemical compounds, the most important military use being fulminate for the detonation of high explosives; there is no known substitute although means for economizing on it are practised. The most important mechanical use is in electrical goods, such as rectifiers and switching devices. Consumption in mercury vapor lamps is now being largely increased by the widespread popularity of the new fluorescent tubes.

Nickel is listed as a strategic material. While there are no producing mines within the United States, from 80 to 90% of the world's production comes from the Canadian mines of the International Nickel Co. of Canada. The United States normally imports about half this, and since none of the Continental powers are able to draw upon the Canadian supply for their customary amounts, a comfortable surplus for the British and American metallurgical industry should always be available. Some American steel makers have been unable to secure more than two or three weeks' supply in advance, but this is probably due more to strict control by the British government than to any present or anticipated shortage.

Platinum is now listed as a critical metal. During the World War of 1914-18 it was a most strategic metal, and in fact a war reserve stock of 27,000 ounces was accumulated at that time, and during the intervening years this had the distinction of being the only reserve supply of essential metal other than gold and silver in the hands of the Government. Meantime the source has completely changed, Canada now being the principal producer as a byproduct of the nickel industry. Adequate supplies should therefore be readily available. Add to this the fact that Alaska has become an important producer since 1938, placer mining at Good News Bay accounting for 66,000 ounces in 1938 and 1939. It is also likely that all requirements could be appropriated from secondary production if necessary, since the normal recovery is 50,000 ounces per year. Inasmuch as 60% of our annual consumption usually goes into jewelry, we would have no difficulty in finding enough for necessary chemical catalysts, platinum utensils, and platinum lined equipment.

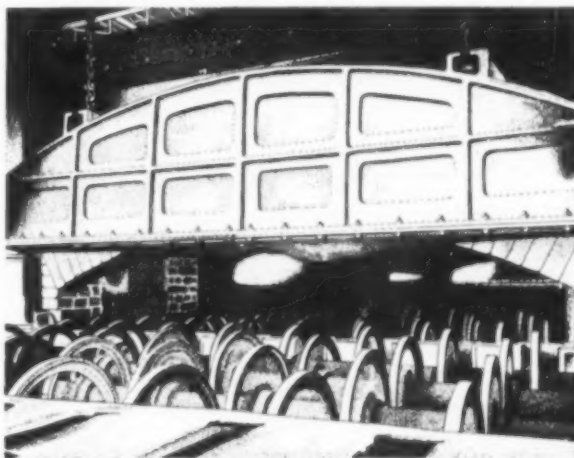
Steel is classed neither as a strategic nor a

critical metal, although both of these adjectives apply in an every-day sense. Our country should be more or less at ease as far as our essential military requirements are concerned, since we now have a capacity to produce more than 84,000,000 short tons of steel ingots and castings out of a total world capacity of 190,000,000. What portion of this 84,000,000 tons will be needed for war, if worst comes to worst, is somewhat problematic, but may be gaged by the fact that Great Britain is now importing steel at the rate of about 7,000,000 tons annually to supplement its own production of 15,000,000 tons. This total of 22,000,000 tons might indicate that one quarter of our total steel capacity would have to be allocated to munitions, leaving 60 million tons of ingot capacity, more or less, for domestic consumption, which would therefore probably not need to be sharply restricted.

T. W. LIPPERT comes to the same conclusion in an extended analysis published in *The Iron Age* for Jan. 23, 1941. Examining accurate statistics of consumption in principal industries, and appraising likely demands and possible capacity to fabricate and consume, he concludes that in 1942 we will be using at the rate of 37,000,000 tons of finished steel for civilian needs and for ship-building and transportation, and 15,000,000 tons for export and defense program. Assuming 70% yield, ingot to finished articles, and steel mill operations at 90% capacity, this figures to a required capacity of 82,500,000 tons by 1942, which we already have surpassed.

One bottleneck (production of highest grade alloy steel for aircraft and other military requirements) has been narrowly averted by the construction of 21 new electric steel furnaces during 1940, raising the annual capacity of the country from 1,800,000 tons to about 2,800,000 tons. Several other furnaces are under order, and the capacity by mid-1941 will be 3,000,000 tons plus.

A similar situation existed in the manufacture of heavy forgings, such as propeller shafts for steamships. This shortage in capacity was also anticipated, and 14 forge companies started expanding their capacity some time ago at a cost of about \$40,000,000. These new facilities will



come into operation at a rate to meet the needs.

Another difficulty exists in the production of extra wide plate for naval use. Only the 206-in. plate mill of Lukens Steel Co. is able to roll plates wider than 160 in. Auxiliary facilities are now being rapidly installed to permit full capacity of this rolling mill, and by summer of 1941 a 150% increase in tonnage is to be expected.

Careful studies have also been made of the producing capacity for armor, ranging all the way from heavy forged armor for battleships to light rolled casehardened armor for aircraft, and furnace and heat treating capacity is being installed at a number of plants to keep in step with expected requirements.

Tin is indeed a strategic metal. Even though its direct use for munitions is minor, the Army lives largely on its stomach, and its stomach is largely provided with food from tin cans. In round numbers the United States requires 75,000 tons of new tin each prosperous year and recovers 25,000 tons of secondary tin from scrap. Approximately one half of this 100,000 tons of tin is used for tinplate, one third the remainder for solder, another third for bearings and bronzes, and a similar portion for tubes, foil and miscellaneous uses.

About 10% of the tinplate for can manufacture finds its way into tinplate scrap from which nearly all of the tin is recovered by the detinning process. However, the cost of collecting and cleaning tin cans is so great that no tin has been recovered from them. In the light of what will be said hereafter, the interest in substitutes for tin cans is understandable, but some variety of coating on black plate must be the basis of all substitutions for tin can food containers, else there will be deplorable delays and expense in providing new filling and closing equipment at the canneries. Although electrolytic tin coating saves perhaps one third to one quarter of the tin used in the hot dip process, there is as yet no substitute for the latter as far as the "wet food pack" is concerned, and this consumes approximately nine of the 15 billion cans made by us every year.

There are no producing tin mines on the North American continent, and rather intensive search has failed to develop any interesting prospects. Nearly all of our tin comes from Federated Malaya States near Singapore and the Netherlands East Indies. In view of our utter dependence upon long ocean shipments, the Metals Reserve Co. announced on July 1, 1940 that it would purchase 75,000 tons of tin at 50¢ a lb., a price designed to stimulate production. However, this stock-pile grows very slowly (although private stocks apparently are now growing rapidly, and it is estimated that we have at present 12 to 15 months' supply of tin in sight in the United States).

On Nov. 4, 1940 the Metals Reserve Co. also

contracted with Bolivian producers for 18,000 tons of tin per year for five years in the form of concentrates containing not less than 18% tin. This comprises approximately one half of the Bolivian output, the remainder being under the control of the Patino interests and a ten-year contract to ship to Great Britain for refining. Bolivian ore is already arriving in the United States, and will await refining. The Reconstruction Finance Corp. has promised to finance the necessary smelter, costing \$1,500,000 more or less, but the deal has not yet been arranged.

Since it will take at least six and more likely nine months to build the smelter and refinery after ground has been broken, and our present imports might suddenly be stopped, it is readily seen that the United States can go from a comfortable position to a great stringency very easily and quickly.

In the event that shipments from Singapore are cut off, it is possible that the Patino ore could not get from Bolivia to Great Britain nearly as easily as it could reach America. Under those circumstances the import of all Bolivian ore would give us nearly half of our requirements for new tin. Sharp restriction of unnecessary uses would then help to eke out as long as we had control of the Bolivian output and intervening transportation.

Bolivian ore comes from the mountainous center of South America, far above the timber line. All the ore comes from underground mines, and is concentrated to separate the gangue from the "tinstone" or cassiterite, tin oxide. Unfortunately these concentrates contain considerable sulphide, together with percentages of numerous other metals, so that it is not an easy ore to smelt—in fact, British smelters mix Bolivian with purer ore before treatment. Fortunately we had enough experience with it during the last war to discover how it could be done; the Maurer, N. J., plant of the American Smelting and Refining Co. produced upwards of 100,000 tons of tin by reverberatory smelting to an impure metal which was cast into cathodes and refined electrolytically in a sulphate bath, using methods and equipment quite similar to those for refining copper. The result was 99.8% metallic tin. This plant and another in the United States had to close shortly after the War because no steady supply of tin ore was available, nor could they compete with the foreign smelters which reduced their treatment charges to a minimum.

Tungsten is a strategic metal, presumably somewhat less strategic than during the war of 1914-18 because at that time a tremendous demand for 18-4-1 high speed steel tools existed, whereas we have learned how to substitute satisfactorily plentiful American molybdenum for most of the tungsten. For many years past China has been the largest producer of tungsten ore, but three

(Continued on page 228)

Manufacture **of** **condenser tubes**

Pictorial Story
Made by Van Fisher
at the mills of
The American Brass Company
Waterbury, Conn.



From Molten Metal to Finished Tubes

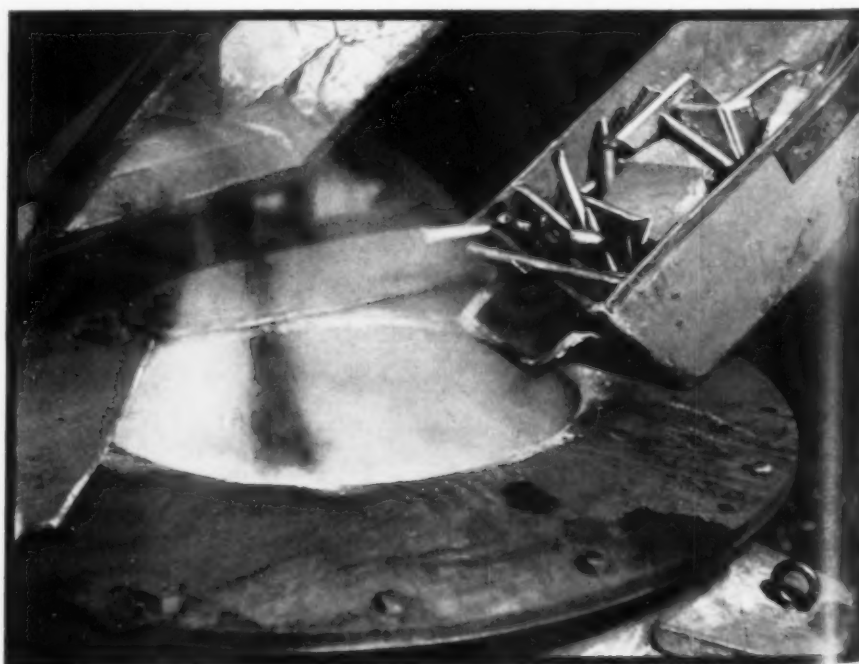




TEN different standardized compositions (copper, copper-zinc, copper-aluminum and copper-nickel) are manufactured into condenser tubes by The American Brass Co. Three different processes, two of which were originally pioneered by the company or its predecessors, are utilized. The one to be pictured here is applicable to tubes requiring the utmost of durability, corrosion resistance, physical perfection and surface condition, namely the alloys containing 30% nickel, and the high brass having 2% aluminum.

Nothing but virgin metal and own scrap from the tube mill goes into the furnace. Cathode clippings of copper or zinc, ingot aluminum or nickel, precisely weighed quantities of minor

constituents are assembled in tote boxes and loaded into the electric furnace. Ajax-Wyatt furnaces, which melt and superheat the alloy by electric currents induced in the metal, each take about 700 lb. of such a charge.



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IN ABOUT AN HOUR the charge is properly melted and alloyed. Electrical input is reduced and the furnace picked up bodily and transferred to the casting floor, where it comes to rest alongside a row of "cannon" molds, so called for their resemblance to Civil War ordnance. These round molds, set vertically, have a "runner box" or pouring basin set on top which breaks up the rush of metal from the pouring lip of the furnace into a dozen small streams falling straight down without hitting the side walls. The workman keeps back the protective charcoal, floating on the charge inside the furnace, with a skimmer of wood or metal. One mold takes about half the furnace charge; toward the end, the pour is gradually checked so the shrinkage cavity naturally forming in the top of the ingot can be properly fed. At this time a small sample called a "button" is also taken for chemical analysis of the heat and final check on composition.

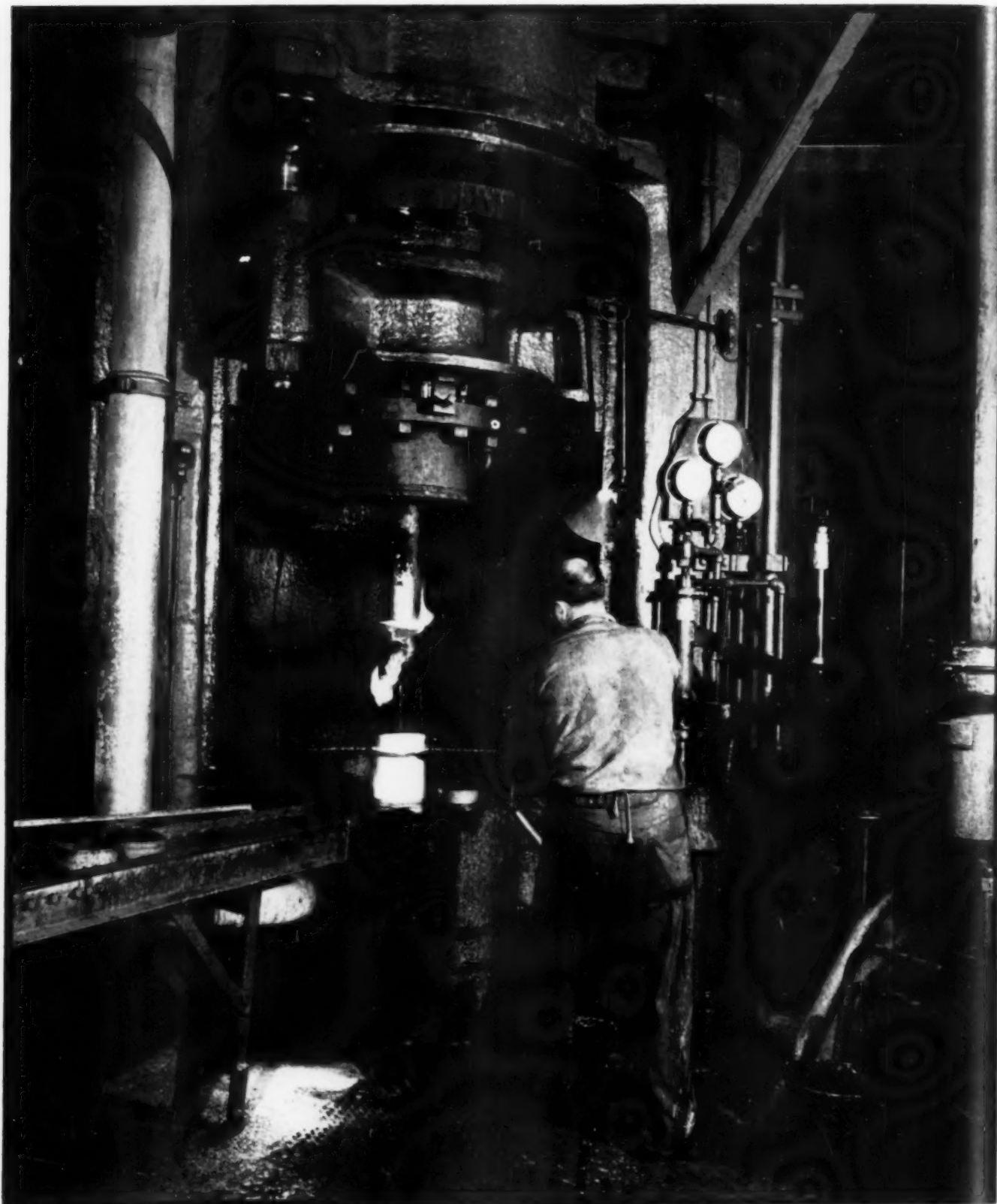




AFTER THE INGOT has solidified, the mold is tilted on its trunnions and the round bar pulled out. Despite careful preparation of mold walls, and use of appropriate washes or coatings, the cast surface contains too many irregularities and imperfections, so it is put into a heavy lathe and some 20 lb. of metal turned off. These cleaned or scalped rounds are then cut into billets in a high speed saw so each piece contains enough metal to form tubes of diameter, wall thickness and length to order. Porous metal from the top of the casting is eliminated at this point.

The next operations, piercing and extrusion, are done on hot metal, so first the billets must roll through a continuous furnace, passing from cold end to hot at a deliberate speed and emerging one at a time. Finishing temperatures vary with the alloy and billet size, but in any event are controlled automatically and continuously by modern pyrometry, and the atmosphere adjusted to avoid damage to the carefully cleaned surface.





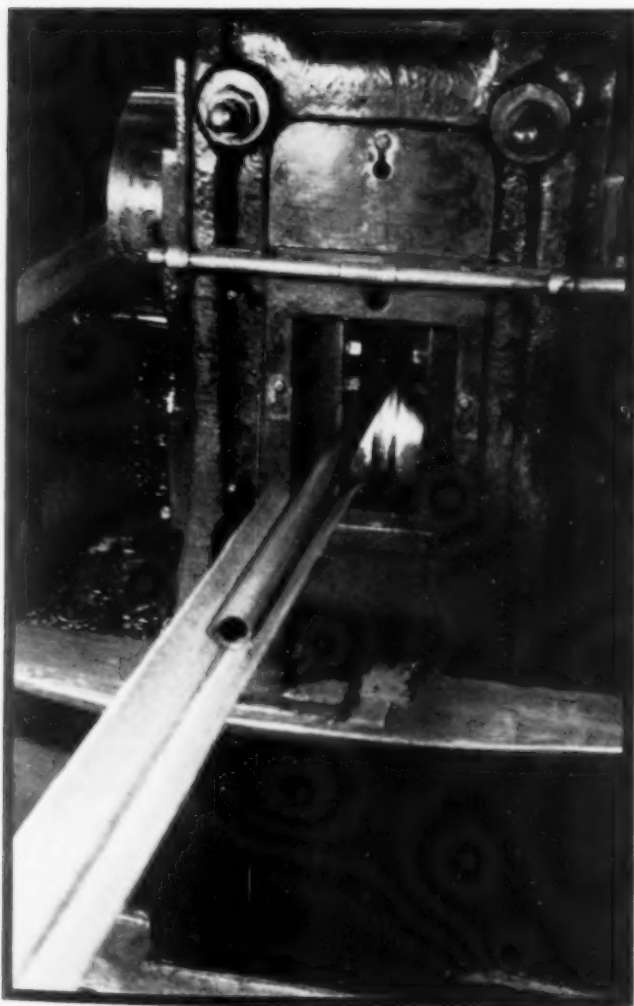
PIERCING AND EXTRUSION are done in a single powerful hydraulic press. The hot billet, say 5 in. diameter and 7 in. long, is placed in the container on the base of the press, and a ram of 5 in. diameter is lowered to close the top of the ring or chamber and hold the billet solidly. This ram consists of an outer sleeve and a central rod or

piercer. This piercer, which may be $1\frac{3}{4}$ in. diameter, is then forced down through the hot billet, and its round end pushes out a core of hot metal through a die in the base of the press. We now have a 5×7-in. billet with a $1\frac{3}{4}$ -in. hole in the center occupied by the steel piercing rod.

The piercing rod remains in place during the

next step, extrusion, and thus forms an inner die or plug to regulate the inside diameter of the tube which is to be formed. The above-mentioned hole in the base of the press, as a matter of fact, is somewhat larger than the piercing rod, being say $2\frac{3}{4}$ in. diameter, and is actually the die that is to shape the *outer* surface of the tube. The tube is now formed by "extruding" the hot metal through the annular space by several hundred tons pressure on the upper surface of the pierced billet, this pressure being transmitted by the outer sleeve. In effect, the top of the chamber full of metal is pushed down so strongly that the hot plastic metal flows out through the annular hole in the bottom into a tube say $1\frac{3}{4}$ in. inside, $\frac{1}{2}$ in. wall thickness, and 3 ft. long. Remnant of metal in the ring or chamber is sheared free below the die, and the die and butt scrap are pushed out, clearing the press for another cycle of operations.

EXTRUDED TUBES are straightened, ends trimmed with abrasive disks, ground outside, and are then ready for further reduction. The tube reducer pictured below looks familiar, but the roll housings have an unusual reciprocating motion and the grooved rolls themselves are tapered or cam shaped. The tube itself is pushed forward slightly, each time in step with the roll



movements, and also turned slightly when free after each back stroke. Inside the tube is a tapered mandrel, and the action of the rolls is to "iron" the metal gradually along the mandrel each time the housing is drawn backward. This machine gives a 70% reduction; the $1\frac{3}{4} \times \frac{1}{2}$ -in. extruded tube will emerge $1\frac{1}{2}$ in. inside diameter, 0.16 in. wall thickness, 10 ft. long.

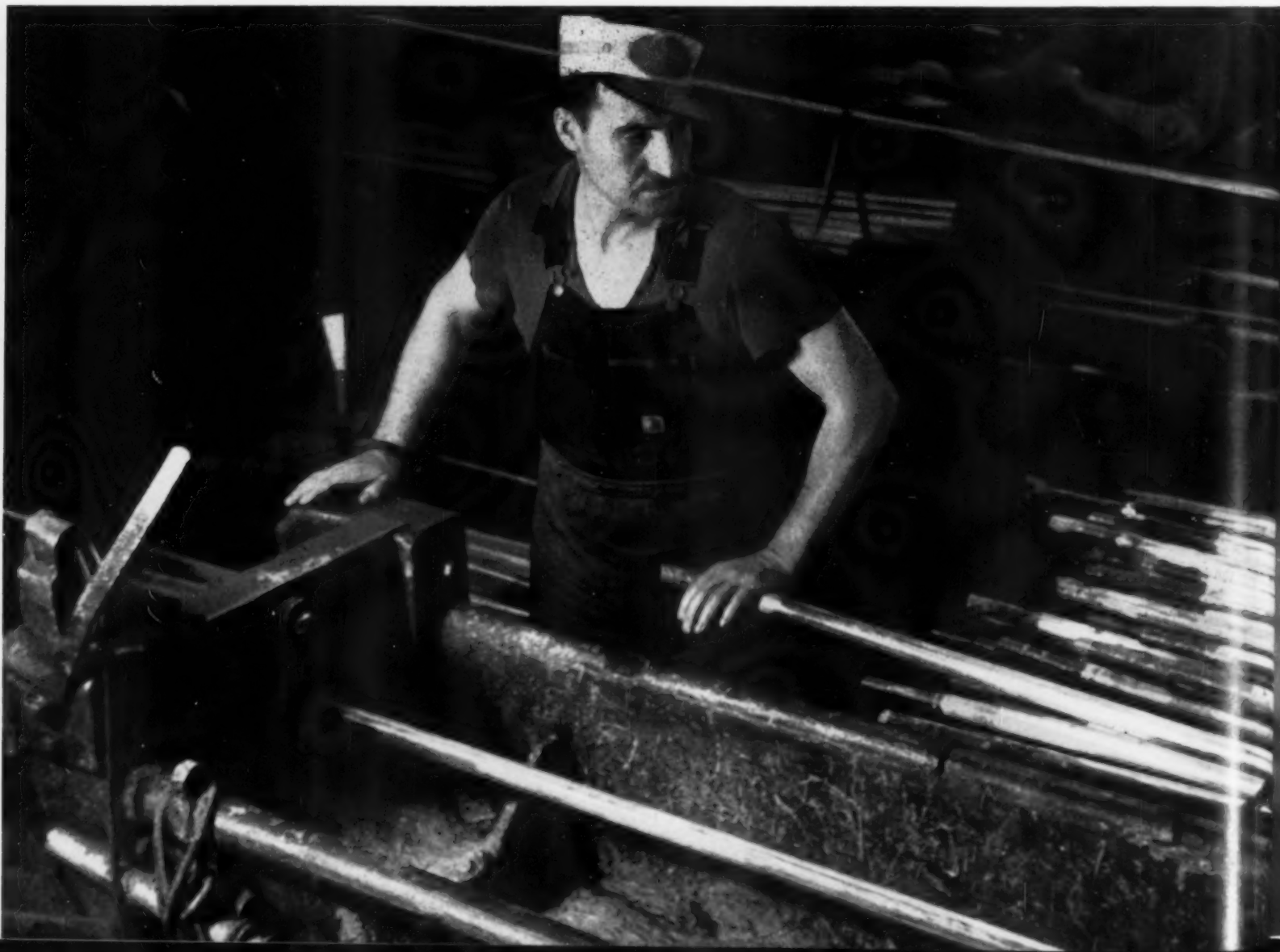


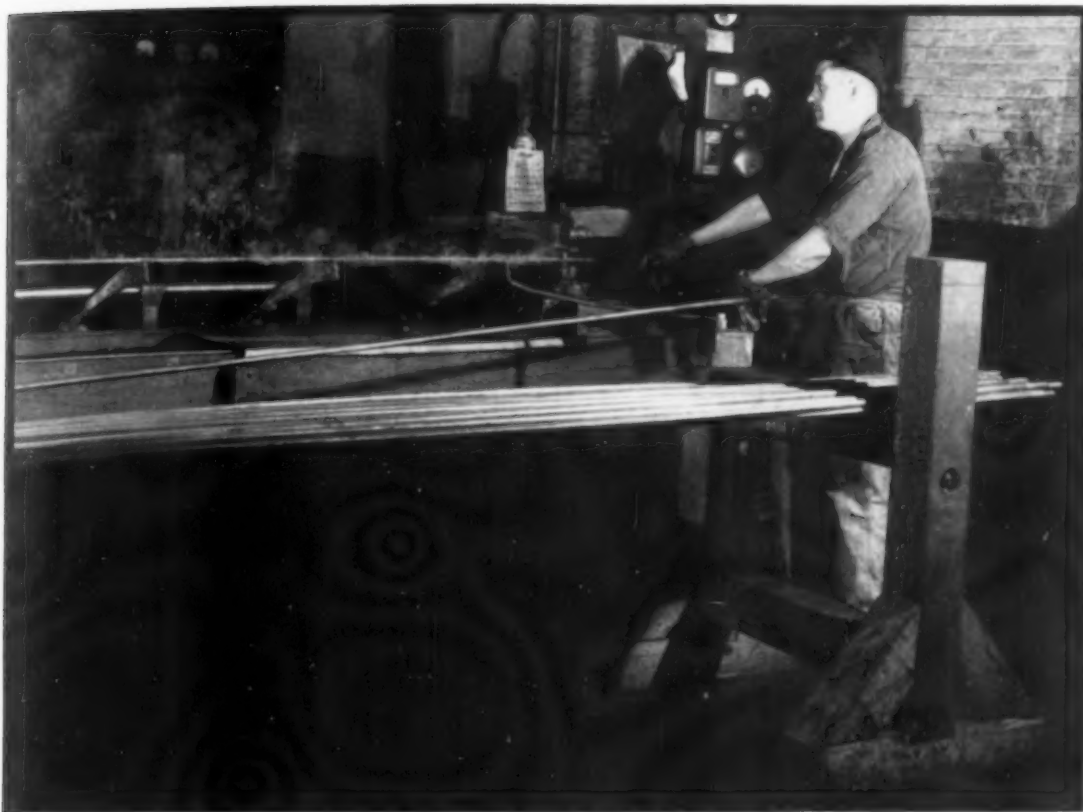
SUCH HEAVY REDUCTION hardens the metal by the cold working effect, and locks up internal stresses; further drawing to smaller sizes is preceded by a softening anneal, done on large batches in atmosphere controlled furnaces.



WHILE ANNEALING is done in a carefully controlled atmosphere, true scale-free "bright annealing" of many copper alloys is uncommercial. However, since these copper-nickel and copper-zinc-aluminum tubes resist corrosion by virtue of a highly resistant film of metallic compounds, it is important that the annealing operation avoid their formation, else the tubes would be very difficult to clean in the pickling bath.

Extruded, rolled and annealed tubes are further reduced to correct size and wall thickness in conventional draw benches, whose construction and operation are too well known to need description here. If many draws are necessary before reaching final size, intermediate annealings and picklings will be necessary.





SCHEDULE of draw-bench reductions and annealings is adjusted so that the last draw gives the tube its desired strength as well as final dimension. Internal stresses set up by this final draw make the tube liable to "season cracking" or lengthwise splitting in certain corrosive situations, so the tubes are treated at low temperature one by one in a Snead electrical annealer. Ends of the tube are gripped by terminals, and a current passed through; the tube is heated by its resistance; it also expands and the current is automatically switched off when it lengthens a predetermined amount.

INSPECTIONS are many, searching, and various. Chemical analyses are frequent. Working and annealing schedules are controlled by the microscopic grain size. Each tube is given a hydrostatic test for stress strength and an air test for tightness. Innumerable stub ends are expanded, flattened and bent to prove "that the metal can take it". Straightness is tested after machine straightening and hand whipping by a skilled operator. Length must be correct, and diameters and walls are micrometered. Visual inspection for slivers, scale or scratches, both inside and out, finally approves the product for shipment.



By James L. Avis
Consulting Metallurgical Engineer
Seattle, Wash.

Remarks on welding, as it is done

THERE ARE MANY of us youngsters who can yet recall the time when we watched with awe and admiration some burly chap who pumped the bellows, heated the bars to sparkling, hammered and welded and fitted a tire to a wagon wheel, or welded a point on a pickaxe, and vaguely wondered if we could ever become such a magician as this man who played with fire and iron and made it do his bidding.

It's a long time between then and now.

In today's mad rush to turn out offensive and defensive equipment, nearly all the metal working industry is developing an orgy of welding. Even in Seattle, this non-industrial western city, the daily papers carry ads of 16 welding shops masquerading as welding schools; some of them guarantee "good jobs as expert welders after a month's course". What would the journeyman blacksmith of old have thought of these "expert welders"? He would undoubtedly have a good word for them, but it couldn't be printed.

Nevertheless, research has come to the fore and demands recognition. It has now been perhaps 30 years since the advent of diversified welding, such as oxy-acetylene, thermit, atomic hydrogen, electric arc, and their application to fabrication in all industry, regardless of type, grade or kind of metals. Industry welcomed the advent of electric arc welding for two main reasons: First, it is far more rapid than riveting, and second, it has greatly reduced production costs. It is always good business to reduce

fabrication costs, but it is always better business to be certain that there exist no attendant hazards.

Probably the most used type of welding today is *metallic arc welding*, in which process an arc is struck between the work (parent metal) and a wire electrode. In principle, the work is short circuited with the electrode at moderate voltage and high amperage, producing heat of sufficient intensity not only to melt the metallic electrode but to bring to fusion the parent metal that is immediately adjacent to the deposited metal. The deposited metal then cannot be described in

any other terms than that it is a strip, layer or bead of cast metal — an idea well recognized by welding engineers in grouping arc welding, oxy-acetylene and atomic hydrogen together under the term "fusion welding".

Now there is a clear tendency, observable by anyone who reads current literature of a semi-technical nature and who attends some technical or engineering meetings where the subject of welding is being discussed, to ignore the fact that a fusion *weld* is essentially a *fusion weld*. Statements have even been widely broadcast by responsible factors in the arc welding industry that if anything is found wrong in a welded joint, it is much more likely to arise from imperfections in the metal being joined than in the joint itself. Such a statement ignores the self-evident fact that most of the material welded is steel in a fairly highly fabricated form and its very existence precludes the possibility of serious defects; drawn seamless tubes, for instance, simply would not arrive at the welder's bench in one piece if not made from sound metal by carefully planned manufacturing operations.

I have only respect and homage to offer the man or men who first conceived and demonstrated metallic arc welding, for it was indeed a boon to industry, having almost countless applications where it is both a time and money saving process and also entirely devoid of any hazards. (By "hazards" I mean danger to life



Exterior View (Nearly Full Size) of Lug Fixed to 1 1/4-In. Tubing by Good Looking Weld

"Mystery in Arc Welding", published last April in METAL PROGRESS. I quite agree with Mr. LINCOLN that it requires no super-intelligence to make arc welds; I have proved that by making a number myself which have been pronounced "good looking" by weldors. However, I doubt if there lives a man who can make a visual inspection of a weld and know whether it is sound, or whether there are so many internal stresses set up by the process of welding that the piece will crack the first heavy blow it receives.

Probably I would not be justified in resurrecting this article from last April's issue, since it was adequately answered by W. J. CHAFFEE (an executive in the welding industry) in a special letter to METAL PROGRESS published in August and entitled "Arc Weldors Must Be Qualified" — as indeed they must — except that a rejoinder to Mr. CHAFFEE was printed in September from the pen of A. F. DAVIS, one of Mr. LINCOLN's associates.

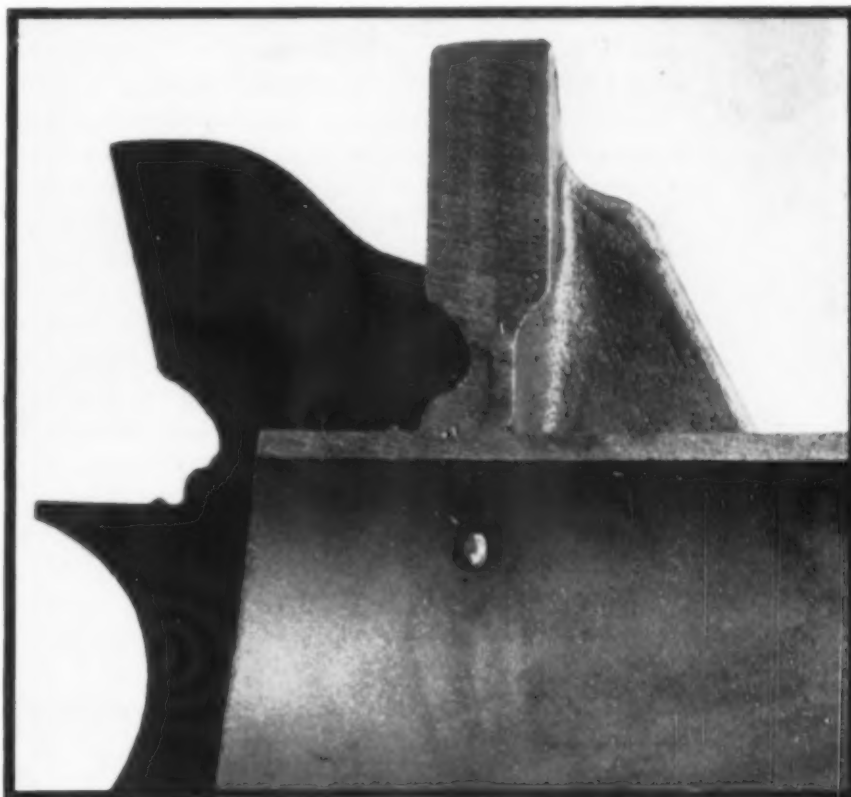
Mr. DAVIS complains that "Many rules, codes, and the like are unduly restrictive, and what is permitted in one code is restricted or forbidden in another." The answer to this is that those who write the restrictive codes actually have some

and property.) It is therefore unfortunate and indeed regrettable that so many able men connected with the welding industry completely ignore all matters relative to the dangers of welding when they appear in public or write for publication. They give minute descriptions of materials, equipment and operating procedure and, if necessary, practical demonstrations, yet they withhold vital information about major accidents that have occurred by a misuse of the process — information that might scare some cautious souls away from welding, it is true, but also information that would enable intelligent men to avoid great grief at some later date.

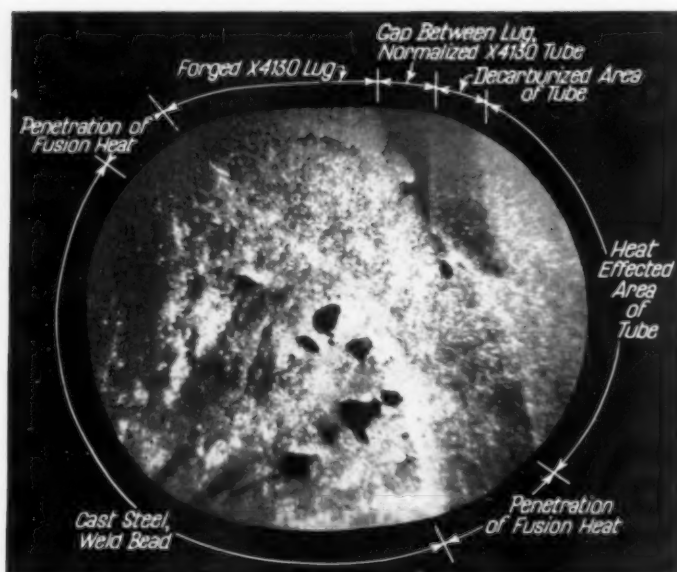
It is all the more necessary to caution those production men (men expected to reduce fabricating costs and increase profits) who are devoid of engineering training, knowledge of testing materials, or the science of physical metallurgy. They have seen, as have all of us, tensile tests of welded joints which break $\frac{1}{8}$ to $\frac{3}{4}$ in. distant from the weld bead. Rarely do such specimens break in the weld. It is but natural that the weldor, seeing his specimen break outside the weld, believes his weld to be stronger than the parent metal. This idea is broadcast and believed, just as the foolish idea that vibration will crystallize and embrittle.

Welding is looked upon by many as just one of the numerous operations daily performed in industry. This is borne out in an article by JAMES F. LINCOLN entitled "No

Saw Cut Through Lug, Weld and Tube, Showing Lack of Penetration to Root of Joint and Porosity. Not polished or etched



definite information regarding welding *as it is done* in the shop or field. All disappointments are not alike; hence the variations in precautionary measures. Further quoting: "We are not in any way trying to cast a reflection on the weldor, as has been implied." To that I would rejoin that the code restrictions do not reflect on the workman as much as the process or the way it is applied practically. I have *invariably* found the weldor honest, sincere, believing in



Macrostructure (10 Diameters, Oblique Illumination) of Weld Near Junction, Showing Cavities and Variations in Crystallinity

himself and his work, and desirous only of making an honest living. Where much trouble hinges is that he has not been given all the information necessary, nor directed with the proper skill.

* * *

This somewhat acidulous preamble was induced by the examination of the welds between a forged lug and seamless alloy steel tubing. Both were made of chromium-molybdenum steel S.A.E. X4130. The weld rod was a flux dipped type (not fully shielded) made of plain carbon steel, carbon about 0.15%. The weldor was a man with ten years' experience on this type of work, of tested ability, considered "an expert". I have reason to believe that the result would be classed as good work, in fact, far better than that produced in many places where welding has recently been embraced as a "modern manufacturing operation".

But let us see what happens when we weld such a steel as S.A.E. X4130. It is one alloy especially recommended for welding and its

composition falls within the following range:

Carbon	0.25 to 0.35%
Manganese	0.40 to 0.60
Chromium	0.80 to 1.10
Molybdenum	0.15 to 0.25

This is indeed a master steel, being used for much of our finest machinery, aircraft and automobiles, and is so flexible or adaptable as to be safely used in five distinctly different physical conditions, namely:

Annealed, with ultimate strength of	80 to 90,000 psi.
Normalized	90 to 115,000
Oil quenched and drawn from 1140° F.	125 to 145,000
Oil quenched and drawn from 970° F.	150 to 170,000
Oil quenched and drawn from 760° F.	180 to 205,000

It is difficult to name a steel that can be so universally used with such satisfaction, unless we add another, chrome-vanadium S.A.E. 6135, that every metallurgist in the world can well be proud of.

Much steel of the type of X4130 is welded, some of it being welded with weld rods of the classic composition of baling wire, others of medium carbon, some alloyed; they are either plain (bare wires), flux coated, or shielded arc electrodes. Their composition or coated or non-coated conditions are not going to be considered in this article, nor the differences between the fusion welding processes used for such steels, whether arc welding, oxy-acetylene welding, or the atomic hydrogen process.

If we wish to forge X4130 we find that the recommended range is 2100 down to 1800° F.; it is never necessary to exceed 2200° F., and in fact if this is done and the inspector knows it, you will have a lot of rejects on your hands, suspected of "burned" metal. (Admitted that the *time* in a forge furnace is long.)

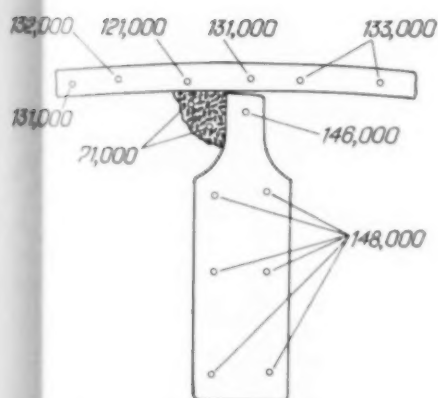
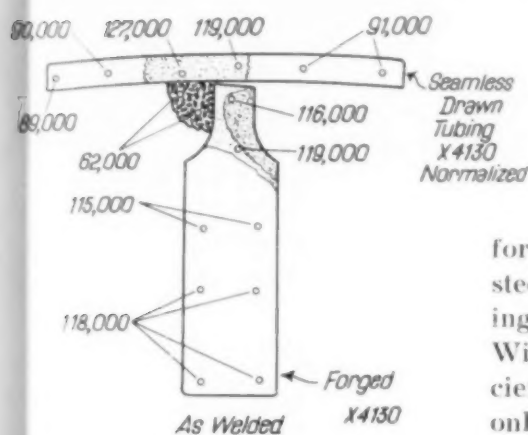
However, when we short circuit a piece of this steel with a welding rod, we do two things: We melt the welding rod and we bring the parent metal nearby to its fusion temperature which is certainly considerably higher than the maximum acceptable forging temperature. Cooling of this steel after forging should be slow, but cooling after welding is a near-quench, due to the absorption of heat by the cold metal surrounding. When welding is over and the welded member has cooled to room temperature, we have two major conditions, namely a strip of metal (the bead) which is

simply cast steel, and the heated zone of the parent metal whose crystallographic structure has undergone a complete metamorphosis, this latter gradually merging into the normal structure of the parent metal. That nearby portion which was heated above 1445° F., the upper critical temperature, transformed into austenite, and on cooling it re-transformed into one of several microstructures dependent on its grain size and cooling rate. (This complicated situation may be understood from an intent study of the "S" curve developed by the research staff of the U.S. Steel Corp. and published as a data sheet in METAL PROGRESS, page 433 of last October's Annual Reference Issue.)

Even the matter of composition is important. When we melted our welding rod we certainly had to



Parallel-Sided Cut Has Removed Slice Through Joined Parts; the Sample Polished and Etched Clearly Shows Heat Effect on Tube and Forging and Coarse-Grained Cast Structure of the Weld Bead



Oil Quenched from 1580°F. Drawn 1140°F.
Hardness Survey Indicates Wide Range of Tensile Strengths (and Inferentially Ductility) in Joint, Both Before and After Heat Treatment

reach a temperature of 2800° F. There is entrapped in the weld metal, due to the surge of the arc, atmospheric oxygen and nitrogen, the latter of which is highly conducive to the formation of iron nitride, a compound that hardens and embrittles steel. When the weld metal freezes, we also have, as in any casting or ingot, primary crystallization, much of which follows the Widmanstätten pattern. This means a coarse-grained metal, deficient in ductility. Lacking the ability to roll or forge this metal, only a thorough annealing can make any improvement in this cast structure, and even such a procedure does not place the weld metal in a physical condition comparable to that of the parent metal. As a matter of fact, many welded assemblies are used as welded; necessarily, there remains an internal structure, highly stressed. ("Stress relief" is a much-abused term, most often used unthinkingly, for the temperature recommended does not exceed 1200° F. Furthermore, the shape and size of many welded members will not permit even the low temperature of 1200° F. without disqualifying distortion.)

We have now welded a forged lug of S.A.E. X4130 to a seamless drawn tube of the same material; the lug was in the "as-forged" condition and the tube had been normalized, that is, heated to 1650° F. and cooled in still air.

We split the tube by sawing and photograph one half of it. (See the first two engravings; page 191.) From the exterior everything looks fine; the view of the saw cut surface gives us pause. The weld did not root clear through to the back of the lug — right there is a sharp notch, a concealed crack. Likewise no eagle eye is needed to see the ample evidences of porosity

within the bead. Yet this welding was done with materials beyond criticism, by an expert weldor, with good equipment, at leisure in a first-class shop! It was a "good looking" weld!

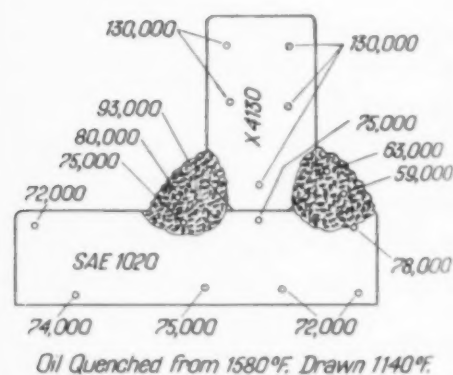
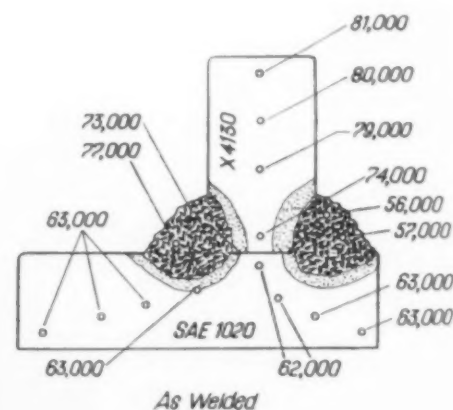
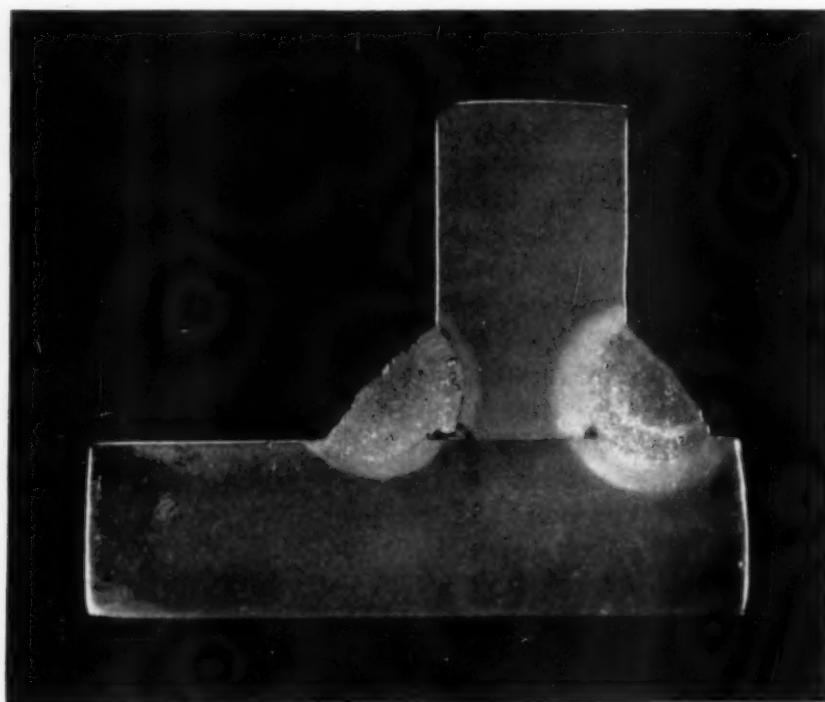
We take the other half of the sample and saw again through it, carefully removing a section $\frac{1}{8}$ in. thick. This is placed on a magnetic grinder, both faces ground, the last grinding operation producing a uniform thickness of specimen, throughout the entire length and breadth. The tensile strengths of the metal may then be determined point to point by conversion from Rockwell hardness tests, the machine having been checked on a standard test block and found correct.

But before making these hardness tests we polish one surface and etch it with picric acid in alcohol, and see what our wonderful little microscope has to show us. First note how clearly the heat penetration has left its mark in changing the structure and etching characteristics of the metal at the joint. Examined under modest magnification, we can easily find several zones, and these have been appropriately marked. Some distance away, within the bead, we see something extremely dangerous, fully as dangerous as a "pipe" or "lamination" in the primary metal, namely a cold shut. To those friends who have read thus far, and who dismiss this weld as a horrible example not indicative of ordinary production, I can only say that nearly all the welds that come to my attention are parts of machinery or equipment

that has failed, and *this is the kind of welds that I see!*

But assume that a perfectly sound weld had been made, what about the internal stress conditions at such a joint? To get some inkling a hardness survey was made and the results (translated to tensile strengths) are shown in the first line drawing. We find in the tube an average tensile strength of 90,000 psi. except at the heat-affected zone adjacent to the weld, where it has jumped to 127,000. The weld metal itself has 62,000 psi. ultimate strength and $\frac{1}{8}$ in. from this and in the welded lug (X4130 steel) we have 160,000 psi. To expect a unit built up in this manner to withstand reversals of stresses is expecting just too much.

Some of my friends argue against my feeling that such figures as just quoted are indications of high internal stresses. However, they agree that such stresses can be reduced by heat treatment, so suppose we quench and temper the piece and repeat our hardness (strength) survey. Such figures are also given in the first line drawing where we find a (Cont. on p. 226)



Photograph, Full Size, of Joint Between Horizontal Piece of 1020 Steel and Vertical Leg of S.A.E. X4130, Using Low Carbon Rod for Left Bead and Medium Carbon Electrode for the Other. Note characteristic heat effects and influence of heat on strength

By William MacGregor Murray
Asst. Prof. of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, Mass.

Seeing

stresses with

photo-elasticity

For some time it has been known that a number of transparent materials (particularly the modern plastics) show peculiar optical properties when subjected to stress. This phenomenon was first observed a little more than 100 years ago in England by Sir DAVID BREWSTER, who found that stressed glass, when viewed in polarized light, showed beautiful colored patterns. At that time, engineers were not so keenly interested in precise stress analyses as they are today and only a very few practical applications of the discovery were made prior to 1900. However, from the beginning of this century inter-

MAN'S EVER-PRESENT DESIRE to travel faster or to create something bigger and better has stimulated his brain into developing many ingenious contrivances. Most of us accept the benefits of successful researches and enterprises with great pleasure and satisfaction, but few people ever stop to consider the efforts which have been expended in order to produce the many luxuries and conveniences now available in everyday life. People in city and rural districts alike are continually coming in contact with feats of science and engineering which have been accomplished after years of painstaking research, carried on quietly in the laboratory and often behind closed doors.

Structural and machine design, in common with all other branches of science, have been advanced through discoveries in totally unrelated fields of study. When one is thinking about the design of a large dam or a complicated piece of machinery such as an aircraft engine, it may seem rather far-fetched to the uninitiated to employ polarized light. However, for determining the stress distribution in complicated forms its application provides a simple and quick method of solving what otherwise would be very difficult and complicated if not impossible problems.

est in this optical method of stress analysis, generally termed "photo-elasticity", has increased by leaps and bounds. This is due in part to the development of better photo-elastic materials, but particularly to the recent invention of "polaroid" which provides a method of obtaining large beams of polarized light.

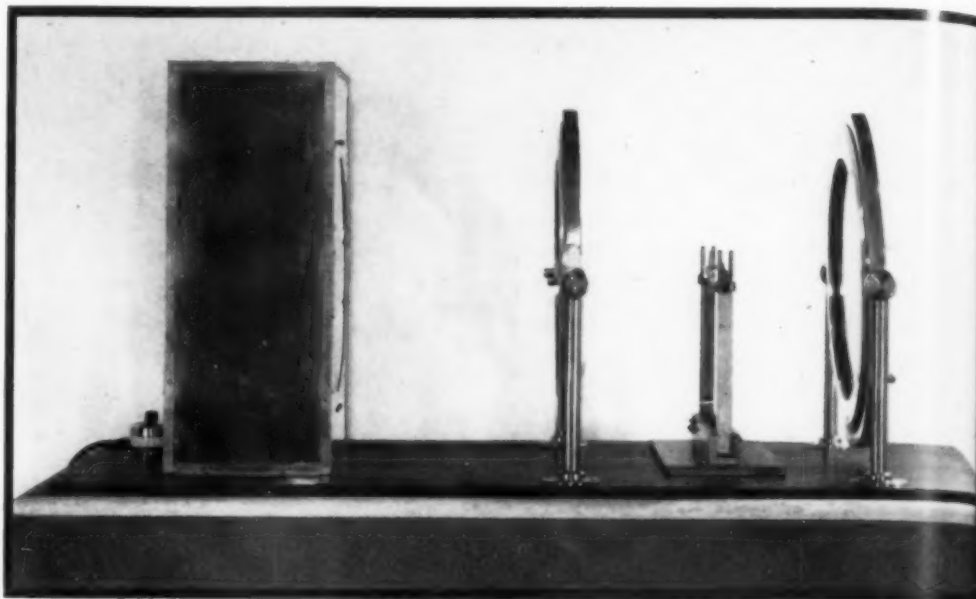
In considering the analysis of stress in a structure the engineer first thinks of mathematical computations and formulae. Although these represent the more usual weapons of attack, there are many others, and among the latter is photo-elasticity. With this method one makes scale models in some suitable transparent material, usually bakelite or celluloid, and examines them under load in the polariscope. This immediately indicates the dangerous regions of high stress. For those problems involving shapes which cannot be conveniently investigated by analytical calculation this optical method is particularly well adapted; however it is especially suited to the solution of problems in two dimensions and to those three-dimensional problems which can be simplified to two dimensions. In addition, means are now available for its application to many of the three-dimensional problems which cannot be easily or conveniently simplified.

At present the ease with which photo-elasticity can be applied to design problems has made it an invaluable tool for all engineering offices. Furthermore, the cost of the necessary apparatus is now low enough to allow even the smaller organizations to install their own equipment. The first figure shows two views of a modern type of polariscope which can be used for examining models up

to 12 in. in diameter. It consists of a light source and two mounted polaroid disks between which the model is located. The examination is made by looking through the disks in the direction of the light source. For visual inspection the apparatus can be used as it stands, and for photographic recording it is only necessary to add a lens and bellows to form the camera.

Unfortunately, there are a few misconceptions as to the merits and limitations of the method. There is on one hand the group which looks upon it as a cure-all, and on the other hand the more conservative element which looks upon it merely as a qualitative aid. Neither of these points of view is correct; as usual the truth lies somewhere in between. In common with other means for finding stress distributions, it should be used only upon those problems which fall within its limitations, otherwise the results are not likely to be satisfactory. Undoubtedly, its use on problems to which it is inapplicable has already produced disappointment and aroused skepticism as to its value. However, in the proper place it is an extremely valuable and powerful engineering tool, and is becoming daily of more importance.

Although in many cases it is only necessary to determine a qualitative result or to locate a region of high stress, it is possible to make precise determinations of stress and stress concentration factors with photo-elasticity. An application of the method for determining quantitative results is shown in Fig. 2. Here one sees the stress pattern exhibited by a small cantilever beam. The depth is 1.80 in., the thickness 0.384 in., and the fillet radius at the support



is $\frac{1}{4}$ in. In the photograph only the end of the beam next to the support is shown but since this 4 in. of length is the more highly stressed region it is of most interest, particularly since it contains the part with the change of section. The load of 70 lb. was applied 8 in. from the support (off the picture) as shown on the superposed diagram. On the basis that the state of stress is indicated by the arrangement of the alternate bands of light and shade, a casual inspection of the photograph immediately shows a region of high stress at the fillet connecting the beam and the support. Wherever there is a concentration of the lines in any photo-elastic model, one knows that it is an indication of a region of high stress.

The actual stress values along the edge of the beam are shown in the diagrammatic part of Fig. 2. Both the theoretical results obtained from the simple beam formula, $f = Mc \div I$, and those determined from the photo-elastic analysis have been plotted. The dotted line represents the theoretical values of the stress and the full line the actual values. It is interesting to note that the two curves agree up to the region of the fillet where the theoretical analysis gives an untrue picture of the actual facts. Although the ratio, length to depth, of the beam is considerably below the usual limitation of the beam theory, the agreement between the two curves as far as the fillet confirms the reliability of the photo-elastic method and gives one confidence in using it where checks are not available.

In addition to demonstrating the reliability of photo-elasticity this example of the cantilever

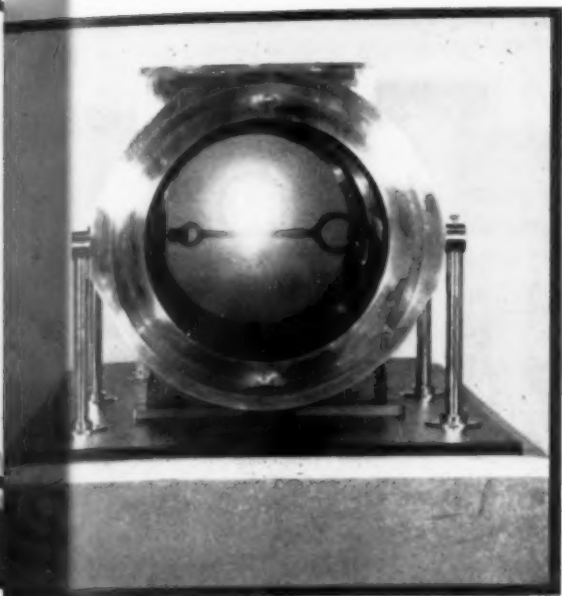


Fig. 1—Side and End View of a Large Polariscopes. The model to be analyzed is placed on the standard between two polaroid disks

in any geometrically similar beam one would just compute the maximum stress from the formula and then multiply the quantity obtained by 1.61, the stress concentration factor, to obtain the true value. Of course, for beams which are not geometrically similar to the one illustrated, this value of the stress concentration factor will not be applicable. However, it has been found that the stress concentration factor is a function of the fillet radius, the depth of the beam, and the depth of the support, and from photo-elastic analyses of beams of various proportions the values have been set up in curves, so that the designer can determine the proper stress concentration factor for any beam.

See "Photo-Elastic Studies in Stress Concentration" by M. M. FROCHT, *Mechanical Engineering*, Aug. 1936.

Since actual stress values have already been quoted, the reader is probably wondering,

"What does the photo-elastic picture mean and how does one interpret it?" The meaning is quite simple and the interpretation is very easy with a little arithmetic.

The dark bands on the picture of the model represent lines of constant difference between the principal stresses, or constant maximum shear stress. The change in the difference between the principal stresses from one line to the next is a

beam demonstrates its usefulness in determining the maximum stress value in a region where computation is difficult or impossible. From this value of the maximum stress one can compute what is called the "stress concentration factor", which is defined as the maximum true stress divided by the maximum apparent stress as computed from the simple theory. For the example at hand the maximum stress computed by the photo-elastic method turns out to be 4350 psi. and that determined by the beam formula is 2700. The ratio of these two values gives a stress concentration factor of 1.61 for this particular case.

What is the use of the stress concentration factor? One sees that in this case the actual stress is 61% greater than the computed value, so that in order to find the maximum true stress

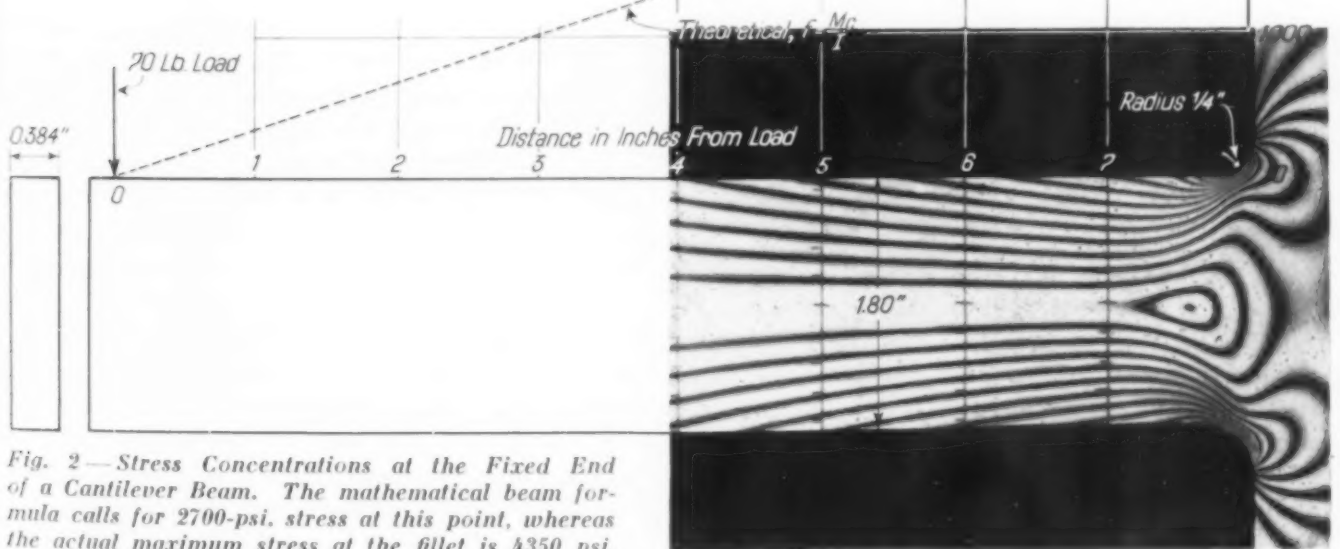


Fig. 2—Stress Concentrations at the Fixed End of a Cantilever Beam. The mathematical beam formula calls for 2700-psi. stress at this point, whereas the actual maximum stress at the fillet is 4350 psi.

constant for a given model (assuming it to be of uniform thickness in the direction of the path of light) and may be determined by direct calibration of the material from which it is made. Hence, in order to find the difference between the principal stresses on any given line, the investigator locates the line of zero difference between the principal stresses, counts lines from there to the line in question, and the stress value is a constant times the number of lines counted.* Another method is to watch the stress lines being formed as the model is loaded and to count them as they pass some chosen point.

As pointed out in "A Review of the Photo-Elastic Method of Stress Analysis" by R. D. MINDLIN in *Journal of Applied Physics* for April and May 1939, there are various methods for separating the two principal stresses within the model but, since the boundary stresses are usually the most severe, one is more likely to be interested in these. On the free or unloaded

*The Editor suggests that "principal stresses" and "constant maximum shear stress" be defined, and while this is difficult to do in a few words, the following may help: Let us think of the two-dimensional problem of a simple plane photo-elastic model. If one considers some point in the model and passes a plane through this point perpendicular to the plane of the model, then on the plane at the point in question there will be a resultant stress produced by normal and shearing components. If the plane is kept perpendicular to the model but rotated about the point, then the resultant stress is found to vary from a minimum to a maximum with the two positions of the plane 90° apart. These maximum and minimum resultant stresses are known as the principal stresses and have no shear components. The maximum shear stress is half the difference between the principal stresses, and occurs on a plane making an angle of 45° with the planes of the principal stresses. For the general case in three dimensions there are three principal stresses on three planes mutually at right angles and the maximum shear stress is half the difference between the algebraically largest and least principal stresses.

boundaries a fortunate condition prevails. Here one of the principal stresses is zero and, consequently, the difference between the principal stresses gives the boundary stress directly. The sign of the stress (tension or compression) can usually be determined from the manner in which the model is loaded, but if this inspection fails to give a satisfactory result there are simple methods available in the laboratory to find out.

Calibration of the material can easily be performed on a small tensile specimen made of it. In this type of model one principal stress will be zero and the other will be

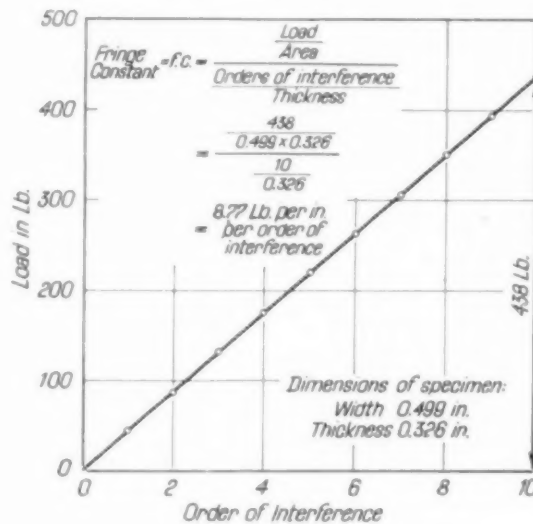


Fig. 3—Typical Calibration Curve for Bakelite, and Computation of the Fringe Constant for This Material

equal to the applied tension divided by the cross-sectional area, so that the experimenter can measure the difference between the principal stresses directly. If the tensile model is stressed and examined in the polariscope with polarized monochromatic light, it is seen to undergo a number of cyclical changes from light to dark and back again during the application of the load. Every time there is a change from one condition of complete darkness to the next, one says that there is a change of "one order of interference". This corresponds to the change from one line to its neighbor on the photo-elastic stress pattern in another model made of the same transparent material. By plotting a graph of load against orders of interference for the tensile model one can find the change in load required for a change of one order of interference, and reduce this to terms of stress from the dimensions of the calibration specimen. If all models were of the same thickness, nothing further would be necessary, but since the order of interference is directly proportional to the thickness of the model, the calibration must also take this into account.

From the calibration a quantity called the "fringe constant" is determined. This may be defined in two ways: (a) The change in the difference between the principal stresses for a change of one order of interference in material of unit thickness or (b) the number by which one multiplies the order of interference at any

point in a model and into which one divides the thickness in order to obtain the difference between the principal stresses at the point in question.

A numerical example will help to make these definitions a little clearer and to illustrate their application. Figure 3 shows a typical calibration curve for bakelite with the determination of the fringe constant (f.c.). The application of the fringe constant to the determination of the stress at some point in a bakelite model under a given load is as follows:

Again using the little cantilever beam shown in Fig. 2 for the example, let us locate some point at which it is desired to determine the stress, such as the point at which the shadowy stress line intersects the tension edge, about 2.6 in. from the support, near where the dimension line appears in black.

First of all, one must locate the line or point of zero difference between the principal stresses and then count lines from this to the point being investigated. In this particular case the zero point is the dot near the center of the beam at the support and counting out from this one finds that the point being considered lies on the eighth line, so that the difference between the principal stresses will be equal to

$$\frac{\text{Fringe constant} \times 8}{\text{Thickness}} = \frac{87.7 \times 8}{0.384} = 1830 \text{ psi.}$$

Since one of the principal stresses is zero at the boundary, this value represents the tensile stress at the given location on the edge of the beam. Reference to the load diagram superposed on Fig. 2 shows that this value checks the stress computed entirely independently by the conventional beam formula.

Reduces Assumptions to Certainties

Two other common problems to which this process of analysis can be applied very easily are illustrated. The first of these represents the stress condition produced by introducing a circular discontinuity into a plate under tension. This is the sort of condition which might be set up by drilling a rivet or bolt hole in a tension member. The stress conditions are shown on the cover design of this issue, wherein the artist used the photo-elastic stress pattern but cut the photograph through the center of the rivet hole and used only one-half the pattern.

The other picture (Fig. 4) shows a double-ended eye-bar under tension. For both of these

examples the actual stress values can be computed in the same manner as that used for the cantilever beam and in the case of the eye-bar it is particularly interesting to observe the high stresses around the inside of the hole and at the junctions between the eye and the shank.

Although the photo-elastic analysis is primarily two-dimensional in character, certain recent advances have adapted it to many three-dimensional problems. At present there are two distinctly different methods of approach. One of these depends upon the internal scattering of light in the photo-elastic material, and the other upon a peculiar property of bakelite which permits the so-called "freezing" of the stress pattern in the model.

This latter procedure was briefly described in "Critical Points" last February, and is known as the fixation method. The model is loaded, heated to a temperature slightly above the boil-



Fig. 4 — Double Ended Eye-Bar in Tension Develops Particularly High Stresses at the Inside of the Central Hole, and at the Beginning of the Upsel on the Bar

ing point of water, and then cooled slowly with the load still on it. At the elevated temperature a considerable deflection takes place which can be retained by cooling under load. Upon removal of the load only a very small part of the total deformation is recovered, and in addition the photo-elastic stress pattern is retained,

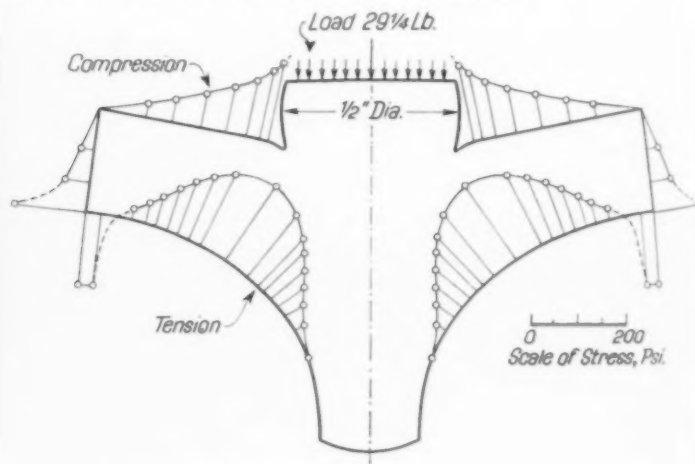
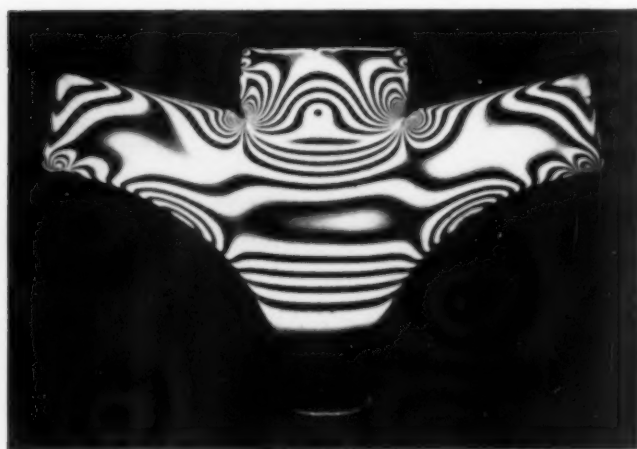
so that the model may be cut up into slices and the stress condition in each slice determined.

Figure 5 shows the practical application of this scheme to a definite problem involving a safety valve disk or stopper. The model is the same size as the prototype and loaded in exactly the same manner. After the heat treatment an axial sheet was cut out and photographed in order to obtain the stress analysis as shown. [A note on the utility of the method to study stresses in rapidly rotating members is appended by Dr. HETÉNYI.]

This discussion only covers a few of the high spots of the photo-elastic method of stress analysis, but the author hopes that he has indicated its definite value as a practical and con-

venient engineering tool which can be applied with the aid of a little simple arithmetic. Although there is much involved mathematics behind the theory, the practical application has now reached beyond the stage of the scientist and the laboratory, and should be of infinite value in producing better designs at much lower analytical and experimental expense than previously considered possible. In this latter respect it is particularly useful in connection with design control, since it can be used to reduce the weight of lightly stressed parts by indicating where unnecessary material can be removed. From many points of view this may be just as important as the strengthening of a highly stressed part. ☼

Fig. 5 — Center Slice From a Full Scale Model of a Safety Valve Disk, Originally a Three-Dimensional Model in Which the Stresses Were "Frozen" by Appropriate Methods



Stresses in Rotating Parts

THERE ARE a number of essential features of the photo-elastic method which make it superior for certain applications to any other current method of stress analysis. It gives results which in exactness are comparable only to those obtained by the mathematical theory of elasticity, while its range of application extends far beyond available theoretical solutions. The fact that the solution of stress problems can be represented in the form of photographs has a great educational value, serves as a guide for the designer, and represents a tangible proof of the solution even for those unfamiliar with exact stress analyses. Not the least, and

from a fundamental point of view perhaps the most important, attribute is however that at present photo-elasticity provides the only existing experimental method of determining the elastic state of stress in the interior of three-dimensional bodies.

At present there are two ways by which three-dimensional stress fields can be so analyzed. One of these makes use of the scattering and subsequent polarization of light passing through photo-elastic materials; the other one enables us to "freeze in" stress lines in the model which can then be cut up and analyzed in any desired section.

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The "freezing" method has been first introduced in this country at the Westinghouse Research Laboratories and has since found various applications in industrial stress problems. It consists mainly of annealing three-dimensional models of photo-elastic bakelite in loaded condition at a temperature of about 250° F. As a result of this procedure the models preserve permanently the elastic stresses and deformation set up by the loading which exists at the annealing temperature. They can then be cut up into small sections, each showing in polarized light the stress distribution in the respective plane of the original piece and by successive slices the stress field can be explored throughout the entire model.

The explanation of this unique case of "solidified elastic deformation" lies in the particular molecular structure of heat-hardening resins. Their structure can be conceived as a strong network whose cells are filled with fusible material, solid at room temperature but melting completely when the temperature is raised to 250° F.

At this temperature the only load-carrying element in the resin is its firm network skeleton; it is deformed through the loading and is kept in that deformed condition by the surrounding filling material as the latter returns to the solid state upon cooling from the annealing process. The result is similar to immersing a steel bar in water and maintaining it in a bent position while the water freezes. The surrounding mass of ice prevents recovery of deformation upon removal of the loading, performing thus the same function as the fusible filling material in the cells of the bakelite material.

The freezing technique can be applied to any model when the loading is steady and does not vary with time. A particular case is the one which acts in a body rotating with constant velocity. The accompanying figure shows an illustration of this kind where the model was rotated with constant speed during the entire annealing process, giving finally a picture of the stress distribution caused by the centrifugal forces in the whirling disk.

"Frozen" Stress Pattern in a Rapidly Rotating Disk Containing Central Shaft Hole and Two Circles of Six Bolt Holes Each





By Oscar J. Horger
In Charge of Railway Engineering
& Research
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Improving engine axles and piston rods

METALLURGIST and designer both are interested in the interpretation of photo-elastic studies, as they are practically applied to the design of commercial equipment made of metal and operating in equipment where failures cannot be tolerated. Several specific cases will be presented to show the manner in which photo-elasticity has supplemented the development of the final product design of some parts in general use throughout the country. Some introductory discussion is prefixed as to the limitations and applications of photo-elastic analysis.

Photo-elasticity provides a powerful means of making a stress analysis but only permits us to determine the effect of shape of the design member upon the stresses. Furthermore, such analysis is confined to stresses within the elastic limit — or, as more liberally interpreted, the yield point strength.

After the best design shape is established from photo-elastic studies, it becomes necessary to choose a suitable material and heat treatment. In this selection, photo-elasticity offers little or no assistance. The ability of ductile materials to redistribute high local stresses, degree of sensitivity of various metals to notch effect, the size or mass effect, residual stresses, surface finish, are all factors which cannot be evaluated from photo-elastic studies.

Photo-elastic values of stress concentration are, for convenience of discussion here, consid-

ered as being applied where a member is subjected to either static loading or a reversal of stresses. In the former instance the stress concentration factors are directly applicable and the load can be predicted at which yielding first occurs, if the material is ductile, or fracture if the material is brittle. Where a member is subjected to a repeated reversal of stresses, the photo-elastic stress concentration factors are always considered as being safe, but are

generally too high unless the member is large; the full value of the concentration factor is considered applicable for a large member because of size effect and general deficiency of knowledge relative to large sizes. For a discussion of "Two and Three Dimensional Stress Concentration and Comparison With Fatigue Stress", see the article by R. E. PETERSON and A. M. WAHL in *Journal of Applied Mechanics*, A.S.M.E., 1936.

Since most failures of parts are a result of the action of variable stresses the following examples will better serve to illustrate the application of photo-elastic studies to this more difficult type of problem.

The design of railroad axles represents one example of where a combination of both photo-elastic studies and fatigue tests have been applied. This problem presented itself by fatigue failures of axles in service, the fracture occurring in the portion where press fitted members, such as wheels, were mounted. The weakening of shafts due to the effect of press fitted members is also experienced in many other types of equipment wherever gears, pulleys, bearings or some form of member is pressed or shrunk on a shaft.

Fatigue failures occur in the axle or shaft just inside the face of the press fitted member. Studies of this phenomenon have been printed by Messrs. PETERSON and WAHL ("Fatigue of Shafts at Fitted Members" in *Journal of Applied*

Mechanics in 1935) and by the present authors in *Transactions* 1937. It appears that the pressure between a sleeve or hub and an axle, when the axle protrudes at either side, is not uniform but increases rapidly near the end faces of the sleeve due to the extra compressive resistance of the protruding portions of the axle. When the assembly rotates under load a further complication arises, for the contraction and elongation of the external fibers of the axle shaft, acting as a beam, cause a minute sliding action of the fitted surfaces near the end faces of the hub, produce a band of abraded metal on the shaft and enhance corrosion at that region. Such "fretting corrosion" at forced fits was described briefly in *METAL PROGRESS* for May 1939 and a more complete account of "Chafing Fatigue Strength of Some Metals and Alloys" was given by GEORGE SACHS and P. STEFAN to the convention last October.

Previous standards and conventional practice for railway axle design, some of which have existed for about 50 years, are just now being modified to conform with the results of findings from the type of researches that are described in the above mentioned publications.

Such studies were first initiated in the physical laboratory of Timken Roller Bearing Co. by preliminary fatigue tests of scale-size axle and wheel assemblies wherein the axles were scaled down to 2 in. diameter. Fatigue values obtained were so low that some explanation was sought for this weakness as well as means for improvement. Standard rotating beam specimens indicated an endurance limit of 39,000 psi. for S.A.E. 1045 plain carbon steels, yet scale-size axle and wheel assemblies of this axle steel had an endurance limit of only 13,000 psi. As a first step a photo-elastic investigation was conducted on a series of plastic models made to various shapes of wheel and axle assemblies. Qualitative rather than quantitative analysis was made from a large number of such studies, of which representative photographs are shown. Interpretation of these photographs in terms of relative strength is not possible because this type of prob-

lem involves the weakening effect due to both (a) stress concentration from the shape and (b) rubbing corrosion between the fitted members. Photo-elastic analysis gives the value for (a) and not for (b), but does indicate means of reducing the effect of the latter.

Figure 1 represents the stress pattern for the conventional design of axle and wheel assembly, showing the axle under a combination of both vertical and thrust loading. The local region of high stress concentration in the axle as circled is enlarged in Fig. 2 and the plane of fatigue fracture in actual axles occurs in the portion indicated by the nest of closely spaced, sharply curved fringes. Corresponding enlarged views of stress conditions for improved designs of axles are shown in Fig. 3 and 4. In the former, the axle is relieved or made smaller in diameter in the portion protruding beyond the wheel fit, and in Fig. 4 an annular relief groove is machined in the axle adjoining the wheel hub face. While the fringe arrangement in these two figures is somewhat similar to that in the first, it should be noted that the localization of fringes occurs at the end of the raised wheel seat on the axle. At this corner on the

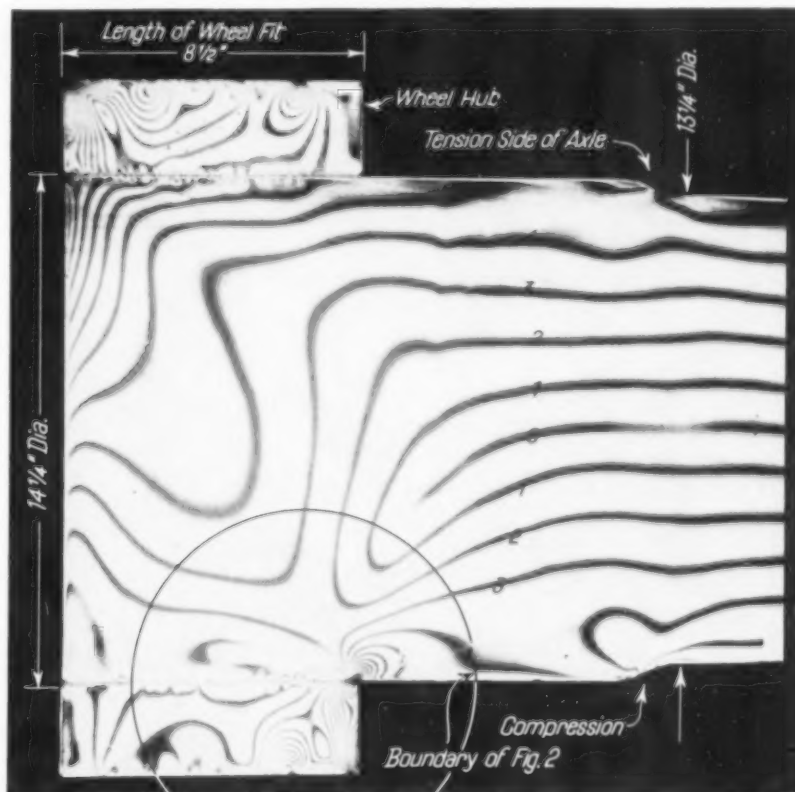
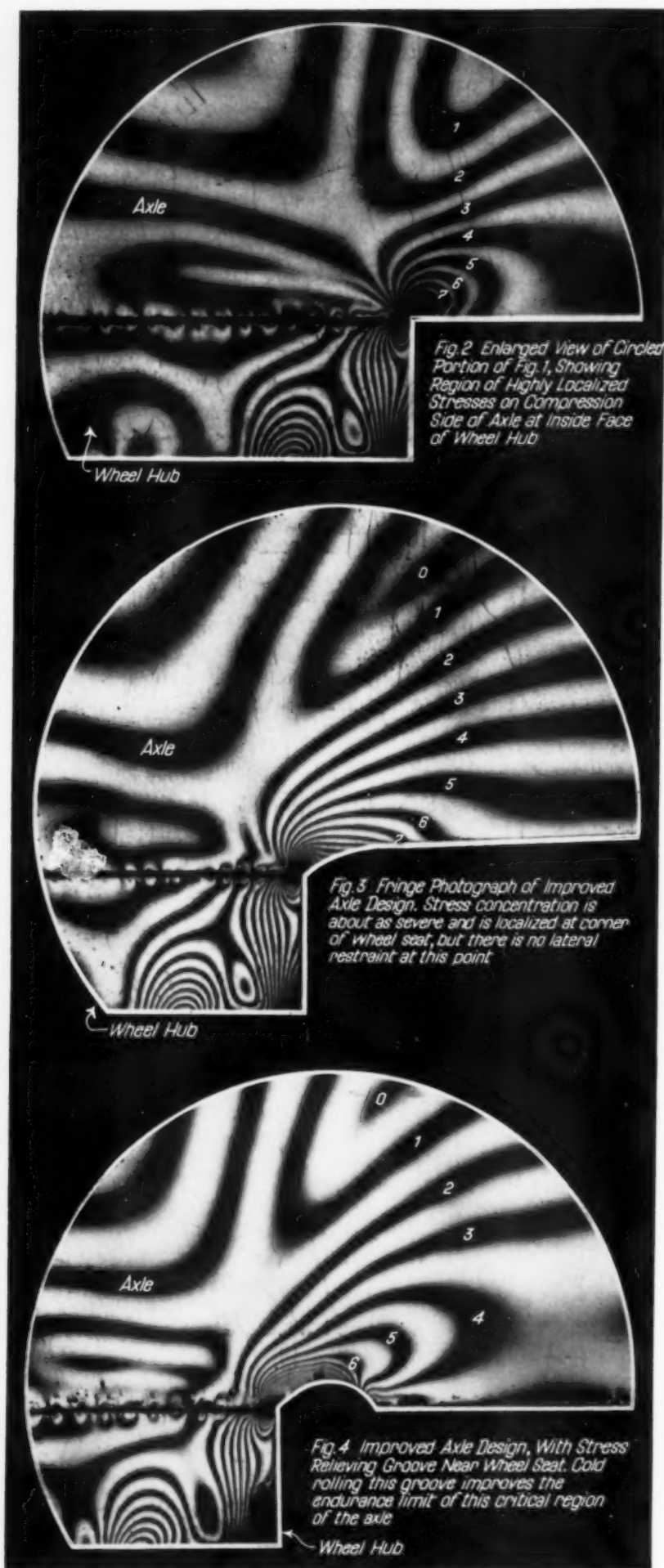


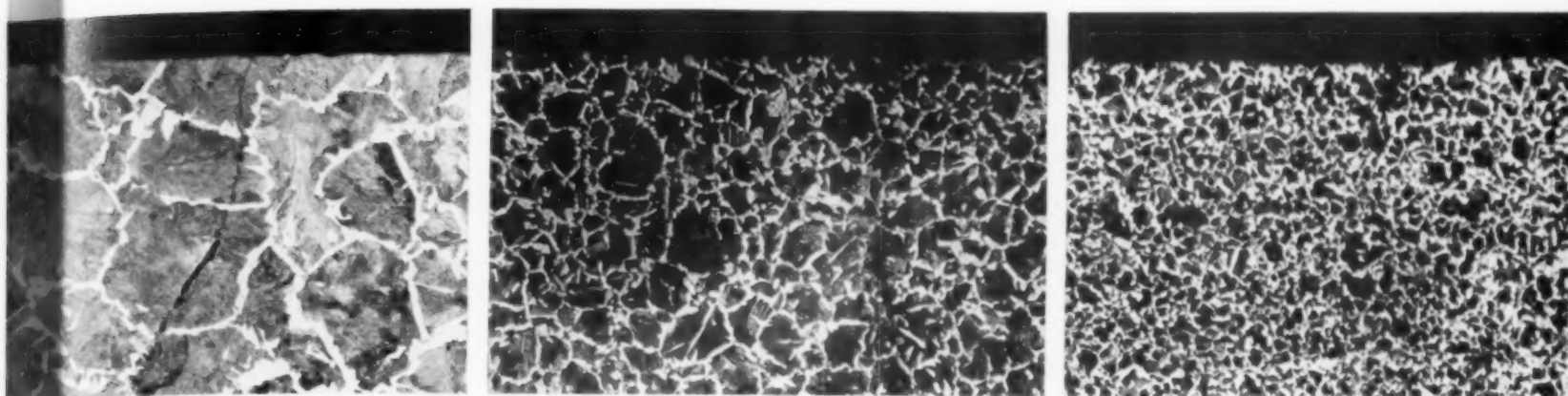
Fig. 1—Fringe Photograph of Model of Conventional Railroad Car Axle and Wheel Assembly. The portions representing wheel hub are squeezed to the axle with calibrated springs simulating the forced fit and the axle is loaded in bending, as in service



axle there is no lateral restraint to permit high stresses to build up; furthermore the axle bending stresses are a minimum in the vicinity of the end of the wheel seat where the weakening effect from rubbing corrosion is the greatest.

Fatigue tests were made in rotating bending of both scale-size and full-size axles of these three designs. In these tests the wheel seat diameter ranged from 1¾ in. to 11½ in., and the results of some of them are summarized in the large table reproduced on the opposite page.

All variable factors influencing these results cannot always be isolated and evaluated. Micrographs of the structural conditions present in some of the test members are shown in Fig. 5. It is apparent that some of the scale-size members do not have the same structure as the full-size members, even though they were taken from the same heat and were untreated after forging or hot rolling. This is a practical condition to be expected from forge shop and mill operations but presents difficulties in trying to isolate the influence of size effect. On the other hand, fatigue tests have been made on scale-size axles which have been machined from untreated full-size axles. In such tests the small axles had fatigue cracks initiating in steel which was originally located considerably below the surface of the full-size axle. Failure originating in such locations means that the fatigue properties of the surface material of the full-size axle is not being determined. Nevertheless, a consideration of the tabular data indicates the danger in applying the fatigue values obtained from small specimens as permissible stresses for the design of large members. It is also obvious that while photo-elastic studies serve a valuable purpose in quickly establishing a design shape of maximum strength, fatigue tests are desirable for determining quantitative values



(b): 1 3/4-In. Scale-Size Axle, Machined From Hot-Rolled Bar
 (c): 2-In. Scale-Size Axle, Normalized and Tempered
 (a): 7-In. Axle, as Forged, Showing Fatigue Crack

Fig. 5 — Photomicrographs of Surface Metal at Wheel Seat of Test Axles, at or Near Places Where Fatigue Cracks Started. All axles made of S.A.E. 1045 steel; contrary to expectation the heat treatment does not noticeably improve the endurance limit. Magnification 75 diameters

of allowable design strength for composite or built-up members.

The manner in which conclusions from this axle research were reflected in product design is shown in Fig. 6, taken from the Fourth Progress Report, April 1940, to the Association of American Railroads on passenger car axles. Here the original design of railroad car axle appears in contrast with the new design where the fatigue strength of the wheel seat is increased as much as 80% with only an increase of 4% in weight, and no change in material or

heat treatment. Change in shape of the wheel seat was responsible for about half of this increased strength, and the addition of metal at the wheel seat was responsible for the remainder.

Driving axles 11 to 14 in. diameter of a design similar to that shown in Fig. 4 or last line of the table have been applied to about 40 modern passenger and freight locomotives. The depth of the relief groove in such axles varies from $\frac{5}{16}$ to $\frac{7}{16}$ in. Also, the bottom portion of the groove is cold rolled to increase its fatigue

Fatigue Test Data on Axles of S.A.E. 1045 Steel

AXLE DESIGN	CONDITION OF STEEL	AXLES WITH PRESS-FITTED WHEELS							PLAIN SPECIMENS WITHOUT WHEELS		
		DIMENSIONS OF AXLE (IN.)					ENDURANCE LIMIT* TO PREVENT		SPECIMEN		ENDURANCE LIMIT
		D	D/d	D/L	R	S	CRACK	BREAK OFF	DIA.	FINISH	
	Norm. & temp. Fig. 5 (c)	2	1.0	1.45			8,000 psi.	13,000 psi.	2	000 Emery	34,400 psi.
	Norm. & temp.	1 3/4	1.0	1.0			9,000	12,500
	Hot rolled Fig. 5 (b)	1 3/4	1.0	1.0			9,000	11,000	1 1/2	000 Emery	31,000
	As forged Fig. 5 (a)	7	1.0	1.0			9,000	11,000	6 0.3	Smooth Turn 000 Emery	17,500 33,000
	Hot rolled	1.89	1.12	1.08	3/4	1/8	10,500	12,500	1 1/2	000 Emery	31,000
	Norm. & temp.	1.89	1.12	1.08	3/4	1/8	10,500	14,000
	As forged	7 3/8	1.12	1.08	2 1/2	1/8	12,000	14,000	6	Smooth Turn	17,500
	As forged	8 1/8	1.20	1.08	5	1/8	13,500	16,000	6	Smooth Turn	17,500
	Norm. & temp.	2	1.08	1.45	5/8	0	19,000	22,000	2	000 Emery	34,400

*Referred to here as nominally calculated bending stress obtained by dividing bending moment in axle at wheel fit by section modulus at same place. Two limits are discernible in this steel; the lower one noted as "crack" starts a crack but the crack does not progress very far; the higher one noted as "break off" will cause complete fracture.

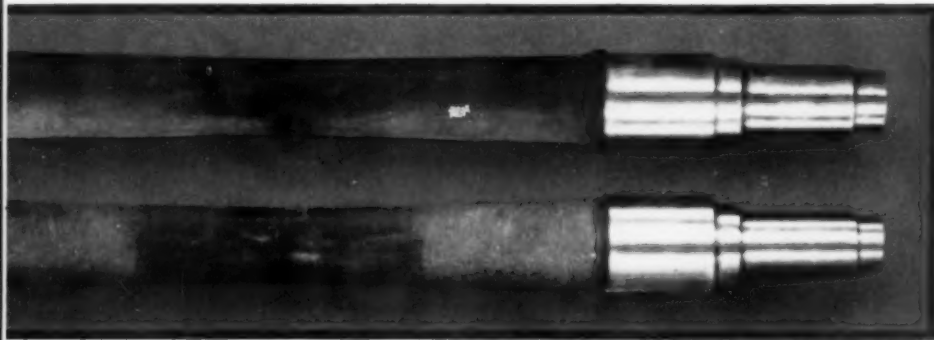


Fig. 6 — Original (Conventional) Design of Railroad Car Axle (Above) Compared With Improved Design 4% Heavier Having 80% Higher Fatigue Strength

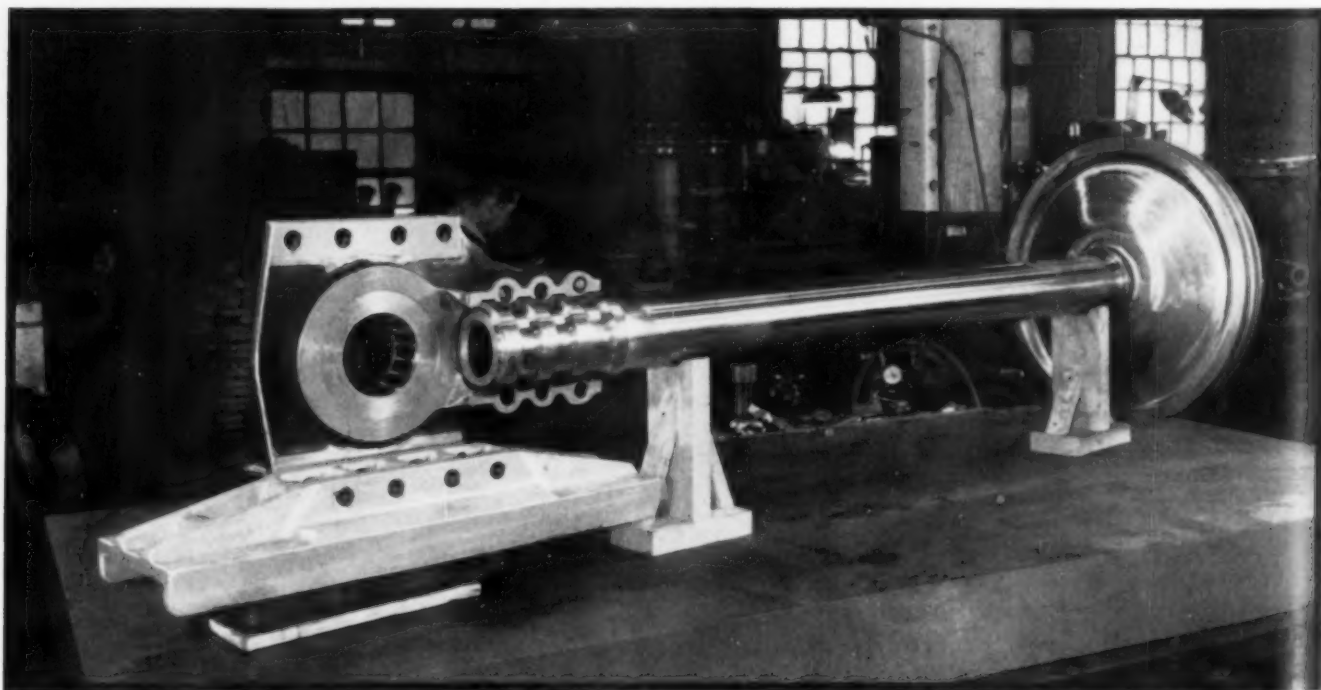
resistance and offset the notch effect, a practice which has been found effective from laboratory fatigue tests. With the laboratory fatigue tests of scale-size grooved axles showing about double the fatigue limit of the conventional design, it is expected that such full-size grooved axles will reflect considerable improvement by longer life in road service.

A further example of how similar design principles have been applied to piston rods for high speed passenger locomotives is indicated in the last engraving. Clamping action of the crosshead on the piston rod is confined to a raised portion or seat on the rod, at which location the tensile stresses from the action of the steam load are a minimum. The extremely light weight of this piston rod is obtained by using thin walled seamless steel tubing, made of a restricted S.A.E. 4340 specification, and it is necessary to minimize the effect of surface

stress concentration by using the most favorable shape. The same practice is followed on the piston rods as on the driving axles previously mentioned with relief grooves, in that the multiple keys on the end of the piston rod are cold rolled as a final finishing operation.

It is often necessary to put holes through the center of cams, rollers, and other parts subjected to diametral loading. There is always the question of how large the hole may be made without endangering failure around the hole from high tensile stresses. This type of problem is ideal for solution by the photo-elastic method, since quantitative values may easily be obtained. Such an investigation reported by O. J. HORGER in *Journal of Applied Physics* for July 1938 revealed that the tensile stress around the hole increased proportionately little in going from a small hole up to a diameter which is about 20 to 25% of the roll diameter. After passing this latter limit, the stresses increase very fast. Repeated impact fatigue tests were necessary, however, to determine the influence of the condition of the material upon failure occurring around the hole. Such tests for two conditions — (a) case carburized hole and (b) hole oil quenched and tempered at a low temperature — showed a much greater repeated impact resistance of the latter over the carburized metal.

Fig. 7 — Partial Assembly of Light Weight Piston Rod and Crosshead. Rod has upset end with circular keyway grooves, cold rolled to improve endurance limit of surface layers



Conversion Tables for Lengths

From "Ready Reference Tables", by Carl Hering

Based on value 1 m. = 39.37 in.

In.	milli- meters	inches	meters	feet	meters	yards	kilometers	miles
1	25.400 1	0.039 370	0.304 801	3.280 83	0.914 402	1.093 61	1.609 35	0.621 37
2	50.800 1	0.078 740	0.609 601	6.561 67	1.828 80	2.187 22	3.218 69	1.242 74
3	76.200 2	0.118 110	0.914 402	9.842 50	2.743 21	3.280 83	4.828 04	1.864 11
4	101.600	0.157 480	1.219 20	13.123 3	3.657 61	4.374 44	6.437 39	2.485 48
5	127.000	0.196 850	1.524 00	16.404 2	4.572 01	5.468 06	8.046 74	3.106 85
6	152.400	0.236 220	1.828 80	19.685 0	5.486 41	6.561 67	9.656 08	3.728 22
7	177.800	0.275 590	2.133 60	22.965 8	6.400 81	7.655 28	11.265 4	4.349 59
8	203.200	0.314 960	2.438 40	26.246 7	7.315 21	8.748 89	12.874 8	4.970 96
9	228.600	0.354 330	2.743 21	29.527 5	8.229 62	9.842 50	14.484 1	5.592 33
10	254.001	0.393 700	3.048 01	32.808 3	9.144 02	10.936 1	16.093 5	6.213 70
11	279.401	0.433 070	3.352 81	36.089 2	10.058 4	12.029 7	17.702 8	6.835 07
12	304.801	0.472 440	3.657 61	39.370 0	10.972 8	13.123 3	19.312 2	7.456 44
13	330.201	0.511 810	3.962 41	42.650 8	11.887 2	14.216 9	20.921 5	8.077 81
14	355.601	0.551 180	4.267 21	45.931 7	12.801 6	15.310 6	22.530 9	8.699 18
15	381.001	0.590 550	4.572 01	49.212 5	13.716 0	16.404 2	24.140 2	9.320 55
16	406.401	0.629 920	4.876 81	52.493 3	14.630 4	17.497 8	25.749 6	9.941 92
17	431.801	0.669 290	5.181 61	55.774 2	15.544 8	18.591 4	27.358 9	10.563 3
18	457.201	0.708 660	5.486 41	59.055 0	16.459 2	19.685 0	28.968 2	11.184 7
19	482.601	0.748 030	5.791 21	62.335 8	17.373 6	20.778 6	30.577 6	11.806 0
20	508.001	0.787 400	6.096 01	65.616 7	18.288 0	21.872 2	32.186 9	12.427 4
21	533.401	0.826 770	6.400 81	68.897 5	19.202 4	22.965 8	33.796 3	13.048 8
22	558.801	0.866 140	6.705 61	72.178 3	20.116 8	24.059 4	35.405 6	13.670 1
23	584.201	0.905 510	7.010 41	75.459 2	21.031 2	25.153 1	37.015 0	14.291 5
24	609.601	0.944 880	7.315 21	78.740 0	21.945 6	26.246 7	38.624 3	14.912 9
25	635.001	0.984 250	7.620 02	82.020 8	22.860 0	27.340 3	40.233 7	15.534 2
26	660.401	1.023 62	7.924 82	85.301 7	23.774 4	28.433 9	41.843 0	16.155 6
27	685.801	1.062 99	8.229 62	88.582 5	24.688 9	29.527 5	43.452 4	16.777 0
28	711.201	1.102 36	8.534 42	91.863 3	25.603 3	30.621 1	45.061 7	17.398 4
29	736.601	1.141 73	8.839 22	95.144 2	26.517 7	31.714 7	46.671 1	18.019 7
30	762.002	1.181 10	9.144 02	98.425 0	27.432 1	32.808 3	48.280 4	18.641 1
31	787.402	1.220 47	9.448 82	101.706	28.346 5	33.901 9	49.889 8	19.262 5
32	812.802	1.259 84	9.753 62	104.987	29.260 9	34.995 6	51.499 1	19.883 8
33	838.202	1.299 21	10.058 4	108.268	30.175 3	36.089 2	53.108 5	20.505 2
34	863.602	1.338 58	10.363 2	111.548	31.089 7	37.182 8	54.717 8	21.126 6
35	889.002	1.377 95	10.668 0	114.829	32.004 1	38.276 4	56.327 2	21.747 9
36	914.402	1.417 32	10.972 8	118.110	32.918 5	39.370 0	57.936 5	22.369 3
37	939.802	1.456 69	11.277 6	121.391	33.832 9	40.463 6	59.545 8	22.990 7
38	965.202	1.496 06	11.582 4	124.672	34.747 3	41.557 2	61.155 2	23.612 1
39	990.602	1.535 43	11.887 2	127.953	35.661 7	42.650 8	62.764 5	24.233 4
40	1 016.00	1.574 80	12.192 0	131.233	36.576 1	43.744 4	64.373 9	24.854 8
41	1 041.40	1.614 17	12.496 8	134.514	37.490 5	44.838 1	65.983 2	25.476 2
42	1 066.80	1.653 54	12.801 6	137.795	38.404 9	45.931 7	67.592 6	26.097 5
43	1 092.20	1.692 91	13.106 4	141.076	39.319 3	47.025 3	69.201 9	26.718 9
44	1 117.60	1.732 28	13.411 2	144.357	40.233 7	48.118 9	70.813 3	27.340 3
45	1 143.00	1.771 65	13.716 0	147.638	41.148 1	49.212 5	72.420 6	27.961 6
46	1 168.40	1.811 02	14.020 8	150.918	42.062 5	50.306 1	74.030 0	28.583 0
47	1 193.80	1.850 39	14.325 6	154.199	42.976 9	51.399 7	75.639 3	29.204 4
48	1 219.20	1.889 76	14.630 4	157.480	43.891 3	52.493 3	77.248 7	29.825 8
49	1 244.60	1.929 13	14.935 2	160.761	44.805 7	53.586 9	78.858 9	30.447 1
50	1 270.00	1.968 50	15.240 0	164.042	45.720 1	54.680 6	80.467 4	31.068 5

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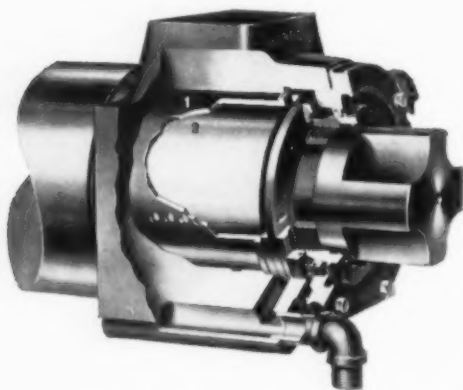


Diagram showing the ASARCOLOY bushing (marked 1) which backs up the Nickel alloy steel bearing sleeve (marked 2). AsarcoLOY is a cadmium Nickel material with a very low coefficient of friction.

This convention exhibit shows how Nickel alloy steel

MORGOIL bearing sleeves are mounted for high speed operation in a continuous strip mill. Production economies and increased output naturally follow the increased abilities of tougher Nickel alloyed materials.

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THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET
NEW YORK, N. Y.

Metal Progress; Page 208

By Harold A. Maloney
Engine Plant Metallurgist
Buick Motor Division
General Motors Corp.
Flint, Mich.

Spark test as a plant control

SPARK TESTING is no news to the ASMember, for it is one of the surest and fastest methods of inspecting metal, of indicating the general chemical composition and the presence of specific alloys, and of checking *every* bar to insure against any tramp iron of the same size and surface appearance. Articles have already been published in METAL PROGRESS and in Metals Handbook on the method of test. Likewise a data sheet in the October issue diagrammed the sparks from the principal types of alloys. However, it may not be amiss to record that the Buick Motor Division uses this convenient test very extensively, in several instances as a 100% check on metal going into a vital part. It is also desirable to note that the test is capable of sharply differentiating between plain carbon steels.

Spark testing is an art, and the accurate use of the test depends upon the skill of the operator. This is especially true when checking slight differences in analyses. The spark tester must watch many conditions in making the test. The selection of the grinding wheel, its speed, the pressure with which the wheel is brought against the steel are all important in producing a spark stream that is easily and accurately interpreted. Spark testing is carried on preferably in a darkened area, since bright light makes the examination of the spark stream more difficult. Some users recommend building a cabinet to enclose the wheel and thus standardize the background and illumina-

tion. This requires that the steel be brought to the grinder and while this is undoubtedly the best way to do it in the laboratory, we find that a portable grinder can be more conveniently taken to the steel for most of the work, and that shop or warehouse conditions are usually such that the test can be accurately performed on the spot.

The most important requisite in making an accurate spark test is the ability of the operator to interpret the characteristics of

the shower of sparks in terms of percentages of chemical elements present in the steel. Each steel will give a spark stream that is peculiar to its analysis. In comparing steels of greatly differing analyses, the nature of the spark stream will show a correspondingly large difference. Carbon, molybdenum, silicon, nickel and tungsten have a characteristic spark that may be easily recognized. The presence and amount of carbon is also easily evaluated. In steels up to about 0.30% carbon, the test is accurate within 0.05% with a skilled operator. In steels of only slightly differing analyses, the differences in the spark stream are naturally not so clearly defined and the test requires great skill for accurate classification. Some soft, non-ferrous metals, such as copper or aluminum, give no grinding sparks in the air.

Sparks from the grinding wheel are, of course, small chips of metal torn off at sufficient temperatures to make them glow, or even kindle and burn in the atmosphere. Some spark streams are long and spike-like, while others are bushy and full of bursts. It is a theory that the sparkles or spurts are due to the rapid formation of gaseous carbon oxides below the surface of the chip (or globule of molten steel) and sudden escape of the gas from inside the globule would cause it to explode. However that may be, carbon is a necessary element for the bursts. Pure iron has very few spurts, while low carbon machine steel yields a few plain forked spurts.

As carbon content increases in plain steel, the explosions increase and assume intricate patterns. They are so profuse in high carbon steel that the spark stream becomes very bushy and particles from the initial explosion dart out and repeat with secondary bursts, producing a branching network of light.

High speed steel is easily identified. Dull color near the wheel and a long spark stream are characteristic. Manganese steel yields a stream of high temperature and great brilliance, while sparks from chromium steel, although similar to those of high speed steel, are of less brilliant color near the wheel and the stream itself is thinner.

As practiced in the Buick plant, spark test-

ing is of great value when steels are used in large quantities and of varied chemical analyses. The spark test is fast, mobile, accurate, and is adaptable to the finished part as well as rough bar stock. It does not replace chemical analysis, but rather is used in conjunction to it as a plant-wide inspection operation. In case of doubt, or to demonstrate, the tester throws a spark stream from a small standard sample of known composition.

Among major items in the spark testing routine at the Buick plants are the 100% testing of all transmission gear stocks to insure the selection of steel against a possible mix-up, and 100% test of all 1335, X1335, and X1340 steels. The latter three items are used in bars of the


The Spark Stream of S.A.E. 1010 Low Carbon Steel, Having a Specified Carbon Content Within the Range 0.05 to 0.15%. The spark stream is thin and there are few bursts

S.A.E. 1050 Steel, Carbon 0.45 to 0.55%. Gives a Spark Stream Similar to the Higher Carbon Stock but With Fewer Bursts. Expert spark testers can easily distinguish the difference, estimating the carbon content to within 0.05%



same diameter and finish and the spark test prevents mistakes in their selection.

Valve rocker arm shaft steel is sparked as a check against the chemical analysis. A percentage of all washer stock is tested to maintain the specification on carbon; high speed toolsteels and high chromium steel of the oil hardening variety are spark tested for alloy content. A percentage of 1020 rivets and a percentage of torque tube stock is tested.

One of the most important uses of the spark test is in connection with the king-bolt stock. The physical properties of the king-bolt are vital to the car's safe operation. The part is carburized and demands a soft-tough core, so the spark test is applied 100% to insure against any high carbon steel being used. 

The Spark Stream of High Carbon Steel Having 0.70% Carbon. The stream is characterized by its bushy appearance and the presence of numerous double bursts or spurts



Cooling of Aircraft Engines

By John Coltman

Abstract from "The Automobile Radiator and Allied Forms of Heat Transference Apparatus", Journal, British Institution of Automobile Engineers, April 1940, page 283.

WHILE aircraft engines and automobile engines are both internal combustion engines, the similarity almost stops there. The competition between air-cooled and liquid-cooled designs has been decided in the modern automobile in favor of the latter and the use of water as a coolant. In aircraft, liquid cooling may be advantageous for certain applications, but it is not essential, as it is in the automobile, due to the very different operating conditions. The airplane has a high enough speed to provide an adequate supply of air for cooling either the finned type cylinders or tubular radiators; the engines are hot and the air is cold so that heat is transferred at a good rate. Silence and low cost construction are not demanded but light weight is; performance is dominant.

Confining attention now to liquid-cooled engines and the radiators therefore, it may be remarked that the name "radiator" is a complete misnomer, as the proportion of heat transferred from the liquid to the air by radiation is small, it occurring almost entirely by conduction. The action of a "radiator" in service appears superficially to be very simple; the hot water from the engine block circulated through the tubes merely gives up its heat to air passing over the hot external surfaces — clearly a straightforward proceeding. In an automobile radiator five different resistances to such transfer of heat occur: r_1 at water-metal interface, r_2 in metal wall of water-way, r_3 in the solder holding water-way to r_4 the metal air-way, and r_5 the metal-air interface. Of these r_2 and r_5 are dominant and are reduced by close fitting of the parts to minimize the solder and improve the joint, and by giving necessary turbulence to the air flow.

It should be remembered that the behavior of the air is different from that of the water. The specific heat of air is 0.24, while the weight per cu.ft. is only 0.08 lb., so that more than 50 cu.ft. of air would have the (Cont. on p. 222)



By The Editor

Critical points

TO THE SOCIETY OF AUTOMOTIVE ENGINEERS' meeting in Detroit, and heard Major General SCOTT, chief of the Armored Force, U. S. Army, describe the organization, equipment and training of our first two armored divisions. Each is a complete army of 11,000 men with 19,000 weapons and 2500 vehicles, and can act independently, having aircraft for observation, light cars for scouting, the main striking force of 274 light tanks and 110 medium tanks, an artillery regiment of field guns, mortars and howitzers to reduce strong points, infantry to hold ground, and appropriate engineers, ordnance, quartermaster, signal and medical corps. Most of the soldiers must be specialists, and a school turning out 500 of them a week is now operating. It takes three months to make radio men and tank drivers from fully trained soldiers — each member of a tank's crew must not

Professional Soldiers for Armored Forces

only have his own specialty, but be able to replace the driver if incapacitated by fatigue or wounds. Methinks this points to a future army of professionals, men who intend to make a life work of soldiering. (In effect the Navy is now so staffed.) General SCOTT said the motorcycle is too fragile and dangerous and will probably be replaced by a bantam car. The present light tanks are so well armored against 0.30 caliber machine guns that ball ammunition has been used against them in practice maneuvers. The American heavy tank is still "on design"; the question is "How shall it be armed and armored?" The projectile now has the upper hand in the "projectile-vs.-armor" argument and the armor is getting thicker and thicker and heavier and heavier, until presently the tank can't move!

CAREFULLY WORDED statements were read by Major General BRETT and Rear Admiral TOWERS, chiefs of Army and Navy Air Corps respectively. General BRETT decried any trend toward lower quality when striving for mass production, saying that since the Germans are masters of fast production, *both* quality and quantity must be achieved for air mastery. Likewise the two are not antipathetic; true quality means easy

assembly and maximum uninterrupted use of such aircraft as exists. (No engineer would cavil with this; the real problem is to distinguish between those places where quality is vital and those where quality is merely ornamental.)

Admiral TOWERS said that three American designs of radial engine give more power than any European air engine, the largest radial developing about 2000 hp. as compared to 1100 for the liquid-cooled unit.

Air Arm Chiefs Discuss Program

(He did not belittle the liquid-cooled unit, saying that it has its place *now*, but that most interest naturally resided in the most powerful engine.) Drag of radial engine has been reduced by research and new designs of cowling and other details, so that craft of "400 honest miles per hour" are now being built. These officers confirmed the disquieting fact that there is as yet no effective defense against night bombing of large areas; the best that can be done is to force the raiders so high with anti-aircraft fire that their aim is zero to poor — indeed that also seems to be the accepted defensive tactics for troops, tanks, and ships. Another disquieting rumor that American aircraft are not good enough for the British Royal Air Forces to use against any fighter craft except the Italians', was said to apply only to those aircraft shipped on French orders while regulations prevented the release of anything except obsolescent models.

DESPITE the humming production of motor cars, one senses that the Detroit region is reorganizing for defense. Truck manufacturers are delivering half their output to Uncle Sam's new army; this requires relatively little readjust-

ment, although the four and six-wheel drives throw a heavy load on axle and transmission plants. Packard V-12 motors for "water wasps" — fast, small torpedo boats — are already in production. Radial engines for tanks and aircraft are months away, but Chrysler's complete new tank factory is about ready to start. Managerial, engineering and supervisory staffs for these new activities are drawn from departmental heads or enterprising assistants in the automotive organization that sponsors them.

Turning Plowshares Into Swords

Metallurgists say their principal worries are to use Government designs and specifications dated 1923 for strictly automotive parts that have been refined by 17 years of close study. One finds such anomalies as these: A nickel alloy steel used without heat treatment for so lightly stressed a part as a hand-operated elevating gear; a shipment of S.A.E. 1120 (which normally would be accepted on faith) analyzed and rejected because it is 0.01% too high in phosphorus, one element that certainly improves its machinability; a \$2 per ton extra charged by steel mills for inspection on any "WD" (War Department) steel, although WD 5120 has an identical chemical specification with S.A.E. 5120; a straightness limitation on axle shafts that must be proof-loaded beyond their elastic limit, yet may not be cold straightened after test. No one wants to compromise on quality where quality is essential, but sometimes the origin or paternity of some requirement seems doubtful — likewise the necessity of building for the years a machine which has a life expectancy of only a few weeks in combat.

To THE vacant Graham-Paige automobile factory, where are exhibited fuselages and wings of two bombers, soon to be produced in the Detroit region, and samples of the hundreds of castings, forgings and fittings required. One is the Glenn Martin B-26, a two-engined ship now in production in Baltimore; it is carefully sectionalized for manufacture, shipment and assembly. The Chrysler organization is planning to make 100 of these bodies monthly in the Graham-Paige buildings. The other main exhibit is one wing and the central section of the four-engined B-24 bomber made by Consolidated Aircraft in San Diego. According to newspaper reports, EDSSEL FORD has offered to stop automobile work in the Rouge plant, if necessary, to build these huge craft — an offer

Bomber Bodies Made in Detroit

in line with the willingness of all manufacturers to subordinate motor car construction to the defense program. The Consolidated bomber is so heavy and the wing structures so complicated by engine nacelles and landing gear hatchways, that this inexpert observer would judge that the limits of riveted aluminum structures are just about reached. Some spot welding may be observed on both craft, but it is confined to such "non-structural" parts as flooring, doors and hatchway frames. Alloy steel tubing, welded and heat treated, makes the engine mounts and landing gear. Inescapable is the feeling of intense refinement of all detail — of the castings and forgings most are required only one per ship; you look a long time to find one whose tag reads "10 required". Mass production, in the automotive sense, simply doesn't apply to these machines in their present embodiment.

WALTER WINCHELLING around the S.A.E. meetings on aircraft engines, discovered that metallurgists in the aeronautical industry may sometimes have to defend the reputation of the metallurgical industry as well as find the best metal for the part. Not that it matters very much, but the question that started the argument was: "What indispensable thing has the steel industry furnished to the modern air engine?" The obvious answer, "Steel", did not satisfy those oil men, mechanical engineers, and aeronautical experts who were baiting their metallurgical confrere. They

Metal for Aircraft Engines

wanted something spectacular, something discovered since 1920 and highly developed exclusively for their use. How about the austenitic steel exhaust valves and the nitrided nitralloy cylinder liners? These are no smaller achievements than, say, high octane gasoline. . . . Recent spectacular achievements in metals are not so easy to find because of the enormous previous advances. Steady progress in quality and variety of fine metals and alloys is much less spectacular but no less indispensable than the rapid growth of the flying machine, which simply didn't exist 40 years ago; at that time the metallurgical industry was already resting on the developments of centuries.

To BUNDY Tubing Co., where RAYMOND HOBROCK, vice-president and chief metallurgist, told me of the development of an idea acquired

by the founder when watching a cigarette-making machine in a Broadway show window. (Perhaps he also noted the decorative operators, to judge from the good-looking girls swarming about the finishing and inspecting benches!) Bundy tubing is made from strip, but instead of merely being turned up and edge welded, the strip is twice as wide as the tube's circumference, so there is a double wall, or a 360° overlap. In its first embodiment, steel strip bent this way was put through a solder bath, then cut to length and twisted and turned into gasoline lines reaching from automobile tank to carburetor — where it was a great success. Some tubing is still so made, but since the perfection of hydrogen brazing, about 1931, most of the product starts as steel strip of precise dimension, electroplated with copper. DAVID KNOX, chief engineer, showed me how a series of forming rolls curls and sizes it over a rod-like mandrel of toolsteel, chromium plated for wear resistance. Cut to 55-ft. lengths, the tube is passed slowly through a G.E. brazing furnace, each length in its own tube-muffle. The atmosphere is made from half-burned natural gas, refrigerated to remove most of the moisture. The original steel strip must be scale-free and the copper deposit free of oxygen or sulphate, else steam bubbles will be

Tubing Made With Ultra- Modern Metals and Processes

formed during brazing, and prevent the joint from forming. Residual stress, or "pinch" from the forming rolls, must also be enough to hold the curl tight during the brazing heat. Such tube may be cold drawn, even down to capillary sizes, but ordinarily is formed into correct size for the intended use — say, $\frac{1}{4}$ in. diameter, more or less. Automatic pressure testing equipment for hydraulic-brake tubing operates much like tin-can testing machinery, although an electromagnetic equipment for discovering flaws may avoid this compressed-air test. . . . HOBROCK showed me their latest development — monel metal tube for Allison engine radiators. This tubing is also of double ply construction when made, but the seams and plies disappear with working and heating and the small sizes are substantially seamless. The base tube is reduced by several unusually heavy passes to 0.230×0.006 in. leaving the tube very hard and stiff. Cut to short lengths, with ends expanded into hexagons, they are nested and joined together by dipping into a shallow bath of sil-

ver solder. Some 10,000 tubes, 9 in. long, are needed for the three radiators to cool the circulating liquid, fuel charge at the supercharger, and the lubricating oil.

TO TIMKEN-DETROIT AXLE plant, where found ROY ROUSH inheriting the duties and emoluments of chief metallurgist from such notable predecessors as HARRY MCQUAID and ORIN McMULLAN, and complaining that the metallurgical work was all but submerged in the drive for production of gears, shafts and axles from such steels as could be purchased and delivered. Nevertheless glimpsed many interesting studies of axles and parts, one being the fatigue testing of full-sized axle shafts in torsion — it being impossible to translate test results from small standard test pieces because of the different nature of the stresses (torsion instead of bending), the questionable stresses due to tapered shaft and flanged or splined ends, and the non-uniform hardness (strength) surface-to-axis after heat treatment. Driving axles, fore and rear, are usually welded housings. Successful butt weld-

Gear Testing, 100% Plus

ing of mild steel plate and tube requires about 85 kva. current and 4000 lb. pressure per square inch of cross-section; if about $1\frac{1}{2}$ times the wall thickness is used up in flash and upset, enough time will be given to pre-heat the surrounding metal and diffuse enough heat for a self-anneal, thus preventing any hardened and embrittled region. . . . Observed one of the pioneering gas carburizing furnaces in action; stacks of 14-in. ring gears of S.A.E. 4620 receive a 0.060-in. case in 10 hr. while passing through a long muffle with gas locks on each end. Small slots in exit doors are opened to remove gears yet prevent infiltrating air from causing some decarburization. Prior to quenching in a press, each gear is wire brushed clean of carbon deposit. Each tooth on each gear is file tested for hardness; the Rockwell hardness may be surprisingly low (sometimes down to C-50) because there is much retained austenite. ROUSH questions the theory that the slightly improved Rockwell hardness of such gears after service is due to subsequent transformation of this austenite, since the microstructure does not change. Cold work hardens pure metals and single-phase alloys by some mysterious mechanism that does not necessarily involve phase transformation, so why cannot it also operate on austenite?

Notes on

important books

A Pioneer, and a Man

Sidney Gilchrist Thomas, the story of an invention and its consequences. By LILIAN GILCHRIST THOMPSON. 328 pages, 5¼ by 8 in., 8 portraits and illustrations. Faber & Faber, Ltd., London, W.C. 1, England. Price 12s. 6d. net.

Reviewed by ERNEST E. THUM

THOMAS it was, of course, who discovered the necessary conditions for the making of steel from high phosphorus pig. It not only extended the application of Bessemer's process to the chief iron ores of Great Britain, Belgium and Lorraine, but the invention also comprised the fundamentals of the basic openhearth furnace — the one which now refines most of the world's steel. The value of the slag as a phosphorus-carrying fertilizer is so great that in one era in England steel became a by-product of fertilizer manufacture.

This account of the inventor and his invention is written by SIDNEY THOMAS's younger sister, who acted as his secretary during the last years of his brief life. The indomitable spirit of SIDNEY — who, even when dying of tuberculosis in an Algerian retreat, experimented constantly with process modifications to make "soluble" phosphorus in the converter slag — this indomitable spirit survives in the sister, who in her 81st year "with failing eyesight and the approaching shadow of death" completed this record of events now historic. Its reading will give some insight into that strange fact that among all Englishmen a watchmaker discov-

ered how to make crucible cast steel, a modeler and designer discovered the pneumatic method of converting molten pig iron into steel, and a clerk in a police court reasoned out the basic refining process, and proved it in crucibles and miniature converters set in his fireplace.

We metallurgists are so interested in the technique of our art and science that we rarely and tardily contemplate the personalities of the men who are responsible for the major advances. This book is of chief interest in this way. SIDNEY GILCHRIST THOMAS, as revealed by his letters to relatives and friends, was a far

sprightlier personality than would be imagined from his contributions printed in *Iron*, a current periodical. "Just had an excruciating conversation with hostess. I am rapidly aging under these efforts. I agree with her, chiefly because it is easier to say *oui*!"

From his reading of patents of all countries, to make sure there were no prior disclosures, and his study of patent law, he became so expert that he instructed his attorney on the fine points. After the basic refining process had been put into operation, THOMAS gave up his court position and traveled as much as his waning strength permitted, keeping in contact with the practices of the various licensees. His letters from his American tours are naturally more interesting to us than the others, although few names are mentioned other than CARNEGIE, FRITZ, HOLLEY, DUDLEY and RAYMOND. He wrote that our architecture was "impressive", and our clubs and restaurants were more pleasingly decorated and advanced in comfort than those in Great Britain. One therefore gathers that as an architectural critic he was a very good metallurgist. His metallurgical comments do not appear.

During his 12 years in the London police court he saw so much misery due to liquor that he became a total abstainer. Dying a bachelor, he put his "bigish fortune" in charge of this sister, with instructions to administer it in such a way as to make the world a better place to live in. The last portion of the book is a report of this stewardship.

To Shape Cold Metal

Plastic Working of Metals and Power Press Operations. By E. V. CRANE. Second edition; 450 pages, 5½ by 9 in., 382 figures and charts. Published by John Wiley & Sons. Price \$5.

Reviewed by JOHN L. BURNS

This is a text or reference book — not one to be consumed in an evening's reading. The approach to the different problems is essentially from the engineering standpoint but the book has considerable metallurgical flavoring. The grouping of different operations makes good classification possible and at the same time renders the subject matter more readable and understandable.

The major portion of the theoretical work of our contemporary physicists has dealt with stresses in the elastic range. Since this book involves the plastic range in all of the operations described, it affords some trail blazing in the development and assembly of theoretical data on the plastic working of metals.

This excellent text book lists and analyzes some 36 practical problems. Since it represents another effort to turn art into science it must be welcomed by all scientists. It will find its way into many of our schools as an engineering text and onto the bookshelves of many engineers and practical men whose job it is to make metals assume shapes. (Incidentally, it would make a good text for one of the training courses in our National Defense Program because of its wide application as to materials and operations.)

"Save the Surface"

Protective Coatings for Metals. By R. M. BURNS and A. E. SCHUH. 407 pages, 6 by 9 in., 89 figures. Published by Reinhold Publishing Co., N. Y. Price \$6.50.

Reviewed by GEORGE E. STOLL

Messrs. BURNS and SCHUH have done a thorough and workmanlike job in their "Protective Coatings for Metals", a new revision of H. S. RAWDON's "Protective Metallic Coatings" published in 1927 in the well known monograph series of the American Chemical Society. Their book, designed to aid in solving problems of metal protection, shows that these gentlemen have a broad command of existing data in this field and they have presented this material in a scholarly yet usable form.

They introduce their problem by a discussion of protective coatings formed naturally, synthetically, or both, and the mechanism of corrosion. They attack the very broad field they have chosen (almost too broad a subject to be included in one book) with an adequate and intelligent review of zinc, cadmium, tin, chromium, copper, lead, the noble, rare and miscellaneous metal coverings. Their discussion of zinc coatings is more detailed perhaps because of its broader usage; in it they take up the hot dip process, electroplating and cementation. After a somewhat briefer account of the organic finishes, paints, enamels and lacquers, they conclude with some remarks on miscellaneous coatings.

That portion of the book referring to methods of testing the various coatings and of the values of these tests is an especially interesting feature, as is their discussion of types of corrosion-testing equipment. The authors suggest the possibility of using statistical methods to separate the effect of constant experimental errors from the effect of variations in the material as a method of furthering knowledge.

The book is well documented and indexed, both as to subjects and authors, and is well illustrated with graphs, tables, photographs, and photomicrographs showing the microstructure of the various coatings.

In short, this book is excellent; an intelligent compilation of the material in the entire field of metal coatings, invaluable as a reference for workers in this field.

Other Good Volumes

ALL THOSE who worry about the supplies of strategic minerals and metals, whether in the United States, in the British Empire, or in the Nazi-dominated areas, will do well to get their facts from "The Mineral Industry During 1939", the 48th annual issue of this publication. It contains the most recent reliable statistics, but unfortunately there are many gaps in the data from Europe. (760 pages, 6½ by 9 in.; edited by G. A. ROUSH; published by McGraw-Hill Book Co., New York; price \$12.)

LAST SEPTEMBER the American Chemical Society's Division of Gas and Fuel Chemistry met in Detroit to discuss furnace atmospheres for metallurgical purposes. The six excellent papers there presented have been mimeographed and are available at \$1.00 from the divisional secretary, GILBERT THIESSEN, 6625 Woodwell St., Pittsburgh.

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Personals

A. B. Kreider ☉, formerly with Lukens Steel Co., is now in the metallurgical department of Bethlehem Steel Co. in San Francisco.

Verner Lindstrom ☉ is now chemist for J. H. Williams & Co., Buffalo, N. Y.

Jim Eng ☉ is on leave of absence from Halcomb Steel Div., called on active duty as 1st lieutenant, Ordnance Dept., at Springfield Armory, Springfield, Mass., on metallurgical work.

D. F. Clifton ☉, who has been doing graduate work at Michigan College of Mining and Technology, is now working in the laboratory of Globe Steel Tubes Co., Milwaukee.

Hugo E. Johnson ☉, formerly research engineer, Battelle Memorial Institute, Columbus, Ohio, is now development engineer, technical development department, Carnegie-Illinois Steel Corp., Pittsburgh.

Richard H. Olmsted ☉ is a special student engineer with Farrel-Birmingham Co., Inc., Ansonia, Conn.

Transferred: R. J. Herbenar ☉, from the Canton plant to the Detroit office of the Timken Roller Bearing Co., Steel and Tube Division.

C. F. Weatherhead ☉ is now assistant refinery maintenance engineer for Trinidad Leaseholds, Ltd., Pointe-a-Pierre, Trinidad, B.W.I.

On leave of absence from Crucible Steel Co. of America research laboratory: Paul V. Bollerman ☉, now serving as 2nd lieutenant in the Ordnance Department at Aberdeen Proving Ground, Aberdeen, Md.

A. S. Kos ☉ has left Truscon Steel Co. to accept the post of experimental engineer with the Research Division of the Aviation Manufacturing Corp.

Henry D. Nickol ☉ has been called from his position as junior metallurgist, Picatinny Arsenal, Dover, N. J., to active duty with the U. S. Army as lieutenant in the Corps of Engineers, Ft. Belvoir, Va.

Transferred by American Brake Shoe & Foundry Co.: C. D. Gibson ☉, from engineer at the Pueblo, Colo., plant to assistant to chief engineer, Ramapo Ajax Div. in Niagara Falls.

James H. Jacobs ☉ is now junior metallurgist, U. S. Bureau of Mines, Boulder City, Nev., working on electrolytic production of manganese.

Elected president of Carpenter Steel Co., Reading, Pa.: J. Heber Parker ☉, formerly vice-president, to succeed the late Fred A. Bigelow ☉.

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**BELL
TELEPHONE
SYSTEM**

THE BELL SYSTEM IS DOING ITS PART IN THE COUNTRY'S PROGRAM OF NATIONAL DEFENSE

February, 1941; Page 219

Personals

C. L. Foreman ☉, formerly assistant chief metallurgist, Buick Motor Division of General Motors Corp., has been made chief metallurgist of Buick's new aircraft engine division. Waldemar Velguth ☉, formerly supervisor of specifications, becomes assistant chief metallurgist.

Fred M. Reiter, long-time secretary of Dayton Chapter ☉, industrial gas engineer, Dayton Power & Light Co., is now a major, Chemical Warfare Service, for one year's extended duty with the first quarter assignment at the Army Industrial College.

J. K. Bybee ☉, formerly in the Indianapolis sales office of Ampeco Metal, Inc., is now in charge of the Michigan territory.

Awarded to A. R. Troiano ☉, professor of metallurgy, University of Notre Dame, and A. B. Greninger ☉, assistant professor of metallurgy, Harvard University, the Robert W. Hunt prize of the American Institute of Mining and Metallurgical Engineers.

Morris Asimow ☉, formerly research metallurgist for Gary Works of Carnegie-Illinois Steel Corp., is now in business for himself in Los Angeles, operating a steel stamping and forming plant known as the Central Metal Products Co.

R. J. Cowan ☉, formerly metallurgical engineer for Surface Combustion Corp., Toledo, is now engaged in the work of the Christian ministry in Lima, Ohio, but is being retained for a time by Surface Combustion on a consulting basis.

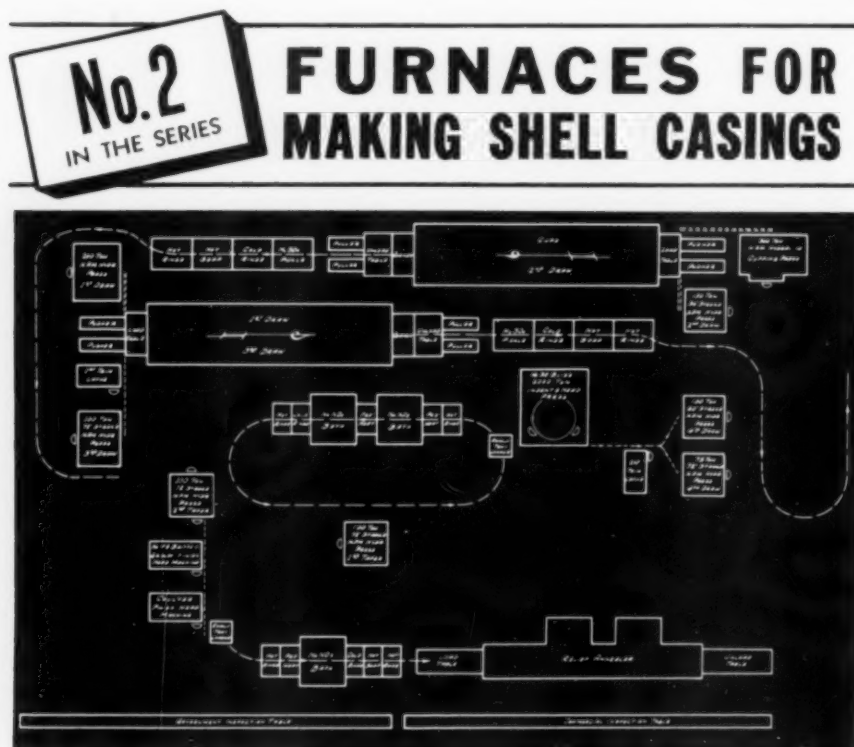
R. Edward Gohier ☉, formerly assistant engineer with International Foils, Ltd., Cap de la Madeleine, Quebec, has joined the staff of Sorel Industries, Ltd., Sorel, Que., Canada.

George H. Thurston ☉, chemist, Bethlehem Steel Co., South San Francisco, has been ordered to active duty with the 6th Coast Artillery and is stationed at Fort Scott, San Francisco.

J. Carlton Ward, Jr. ☉, formerly general works manager, Rome Mfg. Co., Inc., Rome, N. Y., is now president of Fairchild Engine and Airplane Corp., New York.

Honored at a luncheon by Vanadium Corp. of America: George L. Norris ☉, chief metallurgical engineer, on the 32nd anniversary of his association with the corporation and the 75th anniversary of his birth.

Howard J. Middendorp ☉, formerly in the heat treat department of the Caterpillar Tractor Co., Peoria, Ill., is now a junior metallurgist for the Army Air Corps, Materiel Division, Wright Field, Dayton, Ohio.



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Cooling of Aircraft Engines

(Continued from Page 211)

same heat capacity as 1 cu.ft. of water. The disparity is even greater in practice, for whereas the water wets the metal and imparts its heat readily enough, the air is, in comparison, very reluctant to pick up this heat, for air is a poor conductor and

unless every particle of air comes into contact with the hot metal, it will not have its temperature raised to any appreciable extent. The result is that the modern automobile radiator is in effect a series of water tubes which have their exterior surfaces

enlarged from three to five times by passing through sheets of thin metal that act as fins.

This is quite different from the type of cooler that is now usually found on aircraft, namely the "air tube core", "honeycomb" or "cellular" type. This consists of seamless thin-wall tubes whose ends have been expanded slightly into hexagonal shape so they nest closely together although there remain narrow passages between outer surfaces of the round tubes midway. (Seamed tubes are rarely used as they offer such numerous possibilities of failure.) Only the ends of the assembled tubes need be dipped in solder, and the entire honeycomb is then fixed in a proper casing. Set end-on to the direction of motion, the air rushes through the tubes, cooling the liquid which is circulating through the tortuous passages within the cell. As a large surface is available and the construction is light (owing to the 0.005-in. walls of the tubes) these air tube cores were quite satisfactory even in automobile work, despite the obvious loss of efficiency owing to the absence of any indirect cooling surface. In other words the air-metal and liquid-metal interfaces are nearly equal, whereas the first should be much larger.

Tradition dies so hard that the belief is still common that their disappearance in the automotive field is due to the high cost of the seamless tubes of which they are composed, whereas it is due to their comparatively low power of heat dissipation in a car and under normal road conditions, in comparison with the current types of radiator cores.

Owing to the free air-ways, these cores have found their ultimate development for cooling airplane engines. In aircraft design minimum resistance to motion through the air is also an essential consideration. This

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Resistance is referred to as "drag" and varies with the square of the velocity, while the rate of heat dissipation from hot metal to over-rushing air is not quite proportionate to the velocity, so that as speeds increase the drag rises far more quickly than the rate of heat dissipation.

Now that high speeds are eagerly sought, the air flow through the cooling system must be reduced in velocity to an economic figure, and also controlled for proper action during a climb at full throttle but half speed. Until fast speed became paramount, this was accomplished by adjustable shutters. The heat imparted to the air increases its velocity, and if the air exits free from eddies, a propulsive effect should be obtained. Therefore, with proper design, the cooling system should have a negative drag. As a matter of fact, it is now considered that the energy lost in cooling may be recovered at speeds of 300 miles per hr.

The recovery of waste heat mentioned above applies to both air-cooled and radiator-cooled engines, while the former has the advantage of a distinctly greater external temperature difference for the same operating temperatures in the engine. The limiting factor is the provision of sufficient cooling surface on the fins, and so far this has been achieved, at least on radial engines.

In liquid-cooled engines, the search for higher operating temperatures naturally led to attention being paid to cooling liquids other than water. Ethylene glycol has a higher boiling point (386° F.) which allows a smaller radiator, not only due to the higher operating temperature, but also to the fact that glycol picks up heat less readily than water, so that a smaller proportion of the heat from the cylinder is removed. Part of this excess heat goes into the lubricating oil, so it is essential to have a satisfactory oil cooler.

In some cases the heat transmitted to the lubricating oil is exactly double that in a similar engine with water cooling.

In the war of 1914-1918 it became standard practice to use radiator cores made up from brass tubes, $4\frac{3}{4}$ in. long by 10 mm. diameter, about 0.005 in. thick. The higher speeds provided their own solution, for the extra air flow made longer tubes efficient, so that in the early

1930's the tubes generally used were 18 in. long. This resulted in a much more compact radiator which could be partly withdrawn into the fuselage to reduce the cooling. Dimensions of the honeycomb tubes are now varied to suit the performance of the different aircraft, the tendency being to smaller air cells or longer tubes, ratios of length to diameter of 80 to 1 being employed. (Ends on next page)



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Type AA 1000 lb. Detroit Automatic Rocking Electric Furnace with conical shell design.

DETROIT ELECTRIC FURNACE DIVISION
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Aircraft

(Starts on Page 211)

In England the Anderton Brown patent tube is exclusively employed; this tube is hexagonal and designed with differential water-ways, so that its total area is constant. The tubes are solid drawn. Originally, they were of brass from about 0.0055

to 0.004 in. thick, according to the diameter, but now extensive use has been made of cupro-nickel alloys and of copper or very low brass tubes. Copper is used in the United States, but a very small proportion of zinc stiffens the tubes considerably, eases the problems of manufacture, and does not impair the resistance to corrosion. Cupro-nickel alloys are most satisfac-

tory, but costly, especially in small tubes. The strength is important, as high speeds, coupled with rapid changes of direction, severely stress the machine. Monel metal is also used occasionally for tubes.

A good quality tin-lead solder is employed for fixing the tubes into a block; this is usually strong enough and corrosion problems are not serious. Solders with melting points above that of lead-tin solders, but substantially below that of brazing metals, are difficult to work; the most satisfactory seem to be the lead-silver alloys. These run as freely as their competitors, and once a joint is made it is very robust.

Pure tin is satisfactory, but costly, and the melting point is low. Tin-silver and tin-antimony alloys are used; the latter tend to be brittle and crack in service. Zinc-cadmium alloys are also used, but appear to have the same disadvantages.

Oil coolers are made in much the same way. The difficulties are largely in their operation; lubricating oils are by no means easy to cool and the rate of heat transfer may be 50% of that which would be attained with water in the system. Oil is viscous when cold, so that if small tubes are used in the cooler and if it is not operated properly, they will remain permanently blocked. As air temperatures at high altitudes are very low it is essential that the cooler do not congeal in adverse circumstances. A recent development is multi-unit coolers, which adjust themselves very closely to the demands made on the cooling system, each unit cutting in and out as required.

Owing to the high temperatures and pressures which the oil may reach, silver-soldered joints are frequently used. For casings, sheet metal is usually lighter than a casting; to obtain the necessary strength, coolers usually have a round body. ●



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parts between operations,
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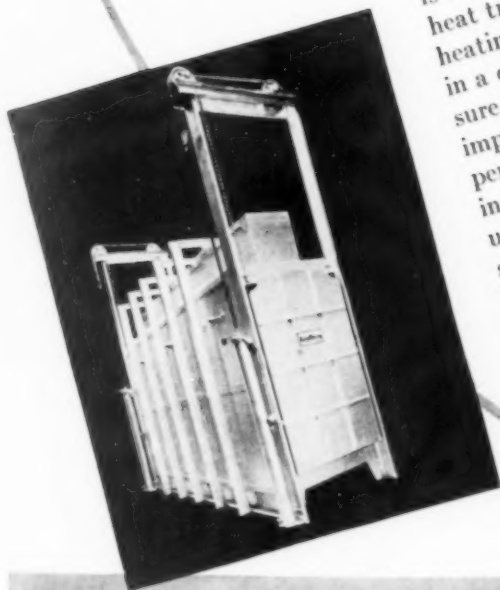
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Welding

(Continued from page 194)

fairly uniform tensile strength throughout the tube except in that area immediately adjacent to the weld bead. The welding operation has undoubtedly resulted in some dilution with the low carbon weld rod for we drop 10,000 psi. at this zone. The weld metal picked up 10,000

psi. from the heat treatment and the forged lug responded admirably. Yet we still have 71,000 psi. tensile of the bead antagonistic to the 148,000 psi. lug and the 121,000 psi. tube.

Wholly irrespective of the question whether heat treatment can remove internal stresses in welds, it is common knowledge that cracks alongside welds have plagued the manufacturers of welded skeletons for small aircraft (made of this very X4130

tubing). The American Welding Society recently published an extended abstract of the literature on this very problem. Where else can such cracks come from except localized internal locked-up stresses high enough to overpower the strength of original metal? The editor of METAL PROGRESS noted it in a Critical Point last December entitled "Crack-Free Welds in Aircraft Tubing" and in conclusion he quoted one of the metallurgists at Wright Field to the effect that it is no easy matter to design, weld and treat an assemblage of tubing, plate and forgings of varying wall thickness and mass, which after oil quenching will have hardness (strength) uniform enough to be acceptable to the Air Corps of the U.S. Army for aircraft parts.

One more example and I have done. The last photograph on page 194 shows an X4130 rolled steel bar with corners mitered and placed vertically on a rolled bar of S.A.E. 1020, welded on both sides, and forming a somewhat lopsided T. One weld at the right was with a very low carbon rod, the other at the left a medium carbon rod. This specimen, like that already shown, has been carefully polished and pical etched. Please note again the marked evidence of heat penetration. The last drawing is also self explanatory, as it shows the physical conditions before and after heat treatment. Micrographs disclosed the expected change of microstructures after the heat treatment.

Let me end on something else than a critical note. My main object has been to call attention to the hazards of welding as it is now done in the shop, and to excite interest in devising ways and means of producing a far more balanced physical condition in welded members. It must and it will be done, for this country has plenty of brains and ingenuity.

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Machines as fast as SAE X1112

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Carburizes like SAE X1020

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Equal to SAE X1020 - X1315 - 1115

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180° Bend (Cold Drawn)

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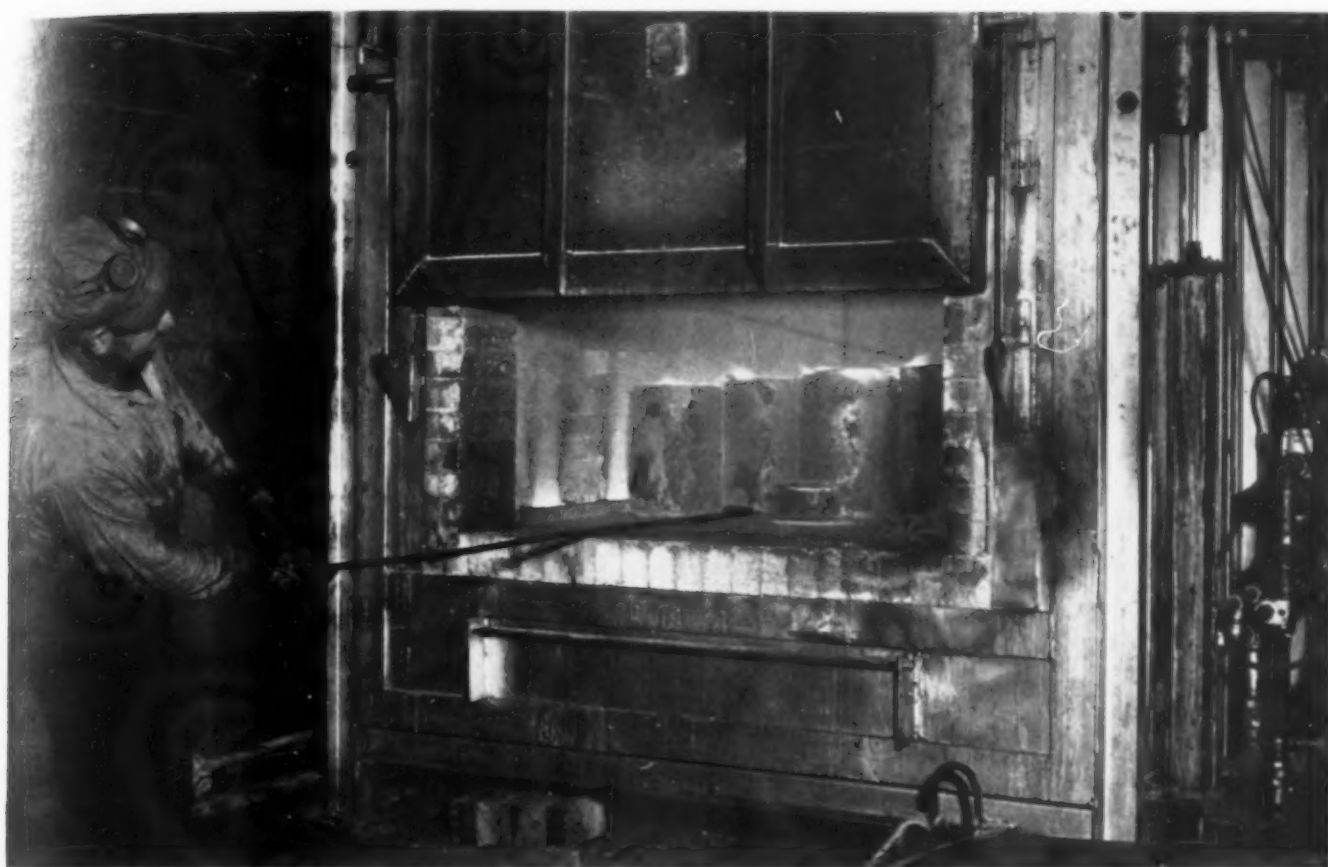
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NORTON COMPANY, WORCESTER, MASS.
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February, 1941: Page 227

War Metals

(Continued from page 180)

quarters of her exports have been stopped by the "Japanese incident". This now puts Burma (India) the leading producer, but England has first call and probably needs it all. Germany stock-piled the metal to a great extent, importing one third of

the world's production during the period 1934 to 1939. America belatedly has announced that we will accumulate \$25,000,000 worth of tungsten concentrates, but the sources for this are rather problematic.

During the last decade, aided by a protective tariff and a gradual increase in price from \$1 per lb. of tungsten in ferro-alloy in 1927 to \$2 per lb. in 1937, Ameri-

can mines, principally in Nevada, Colorado and California, have produced about two thirds of our requirements. Even in the present situation the price of tungsten in ferro-alloy has not sharply increased, yet we are currently producing about half of our needs. Recently a private plant has been built and is now cleaning off-grade concentrates. The Bureau of Mines has also prospected with diamond drilling a big body of low grade, high cost tungsten ore in the Nightingale district in Nevada. All in all, it is anticipated that, with increasing price, large new production in the western states can be anticipated—as it did during the last war.

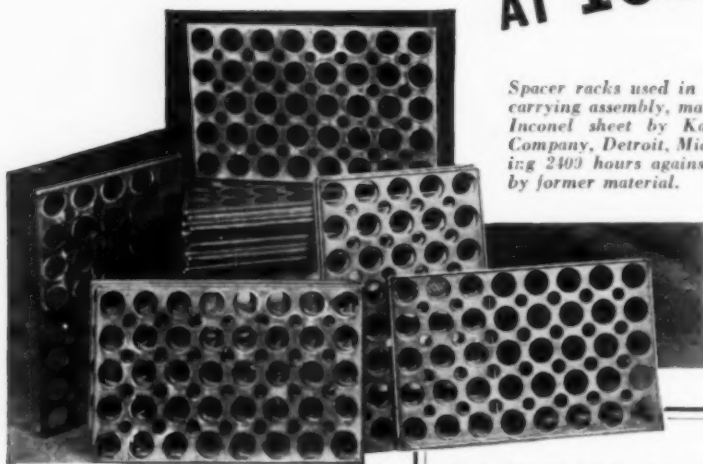
About 95% of the tungsten is utilized by the metal industry. Most goes into high speed cutting tools and other tool and die steels; other important uses are a 3% addition to the austenitic chromium-nickel steel exhaust valves for aircraft motors, and the somewhat higher tungsten content in alloy overlays on valve seats to resist scour of hot gases. Likewise tungsten is an essential constituent of stellite, another tool material, and magnet steels. Tungsten filaments for electric lights are so exceedingly fine that less than 2% of the tungsten used in America is required. However, a much larger and continually growing demand for tungsten carbide cutting tools is to be anticipated.

The United States will probably require about 10,000,000 lb. of tungsten in 1941, of which half can be expected from American production. If supplies from Asia should be interrupted, some 40% of these requirements could be had from other sources in this hemisphere, principally from Bolivian mines in the tin mining districts.

All in all, the situation does not seem too comfortable. It could be much worse if there is a sudden and expanding demand

(Continued on page 230)

INCONEL 2400 vs. 700 HOURS AT 1650° F.



Spacer racks used in pinion gear carrying assembly, made from $\frac{1}{8}$ " Inconel sheet by Kay Products Company, Detroit, Mich. Now giving 2400 hours against 700 hours by former material.

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For carburizing, nitriding and other heat-treating equipment, have you investigated the possibilities of the high-nickel alloy INCONEL?

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CHROME ALLOY

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War Metals

(Starts on page 175)

for tungsten steel for armor piercing bullet cores, or erosion resisting metals for gun liners.

Vanadium is classed as a critical metal although it is estimated we can currently produce from developed mines within the United States some 4,000,000

lb. of 40% ferro annually (very close to the apparent consumption in 1939) and even this can be expanded, given a little time. Most of the American production comes from ore mined in Colorado, although other mines in Arizona and Utah are developed and merely await demand (and price). During the past few years America and Peru have produced approximately equal

amounts of vanadium, and their combined production equals about two thirds of the entire world's production. The Peruvian mine is owned by American interests, and it also can expand its production. Under these circumstances, vanadium appears to be a somewhat less critical metal than others on the list.

Zinc is not listed either as strategic or critical, but a critical situation developed late in 1940, said to be due to large British purchases. At any rate, the visible stock in America is normally equal to about ten weeks' consumption, but at the present time it is nearer ten days'. It is not surprising, therefore, that the price has increased from 4½¢ per lb. as of January 1939 to 7¼¢ per lb. as of January 1941. However, it is more puzzling that U. S. production through 1940 remained fairly steady at the rate of 640,000 tons per year.

Normally we produce (and consume) about one third of the world's production. Our mine capacity and reserves are very large; similarly our rated smelter capacity (600,000 short tons per year by distillation and 214,000 by electrolysis) is about 38% of the world's ingot producing capacity. The lag in the expansion of zinc output may be explained by finding a considerable proportion of the listed capacity by distillation in no condition to operate. At any rate, it is understood that added smelting capacity will be in operation by July 1941. Little expansion in American mining will be necessary, because 250,000 tons of over-seas concentrate, normally smelted on the Continent, cannot get there in 1941.

Zinc, of course, is essential to the brass industry; large quantities are also absorbed in the galvanizing of iron, in the production of die castings, and in rubber manufacture. Of these, the typically wartime production will be for brass shell and cartridge cases.



Improved to meet the demands for rapid fatigue tests, the R. R. Moore high speed Fatigue Testing Machine now operates at speeds of 10,000 rpm. The machine is equipped with a variable speed drive—an essential feature in the testing of certain alloys which heat up when highly stressed and it also allows correlation of high speed tests with previous lower speed tests.

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